

Semantic and Action Influences on Visual Perception

The role of action affordances and object functionality in visual selection, memory encoding and post-perceptual processes.

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DECLARATION

I declare that this thesis has been composed by me, Konstantinos Tsagkaridis, and that the work presented in it is my own. I also declare that this work has not been submitted for any other degree or professional qualification.

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ABSTRACT

The current thesis explores semantic and action effects on visual perception and specifically how higher-level knowledge can co-affect the process of visual perception, along with the well established effects of low level image characteristics, such as colour, image/object saliency and general gist of the scene. Recent evidence on object recognition supports perceptual grouping effects of familiar pairings of functionally interacting objects. This leads to an advantage for their perception as compared with objects positioned in a non-interacting configuration, in cases where there are attentional limitations in perception. Similar effects were previously reported in clinical cases of people diagnosed with neglect (Humphreys & Riddoch, 2001, 2007; Riddoch et al, 2003, 2006), but the fact that they are also present in normally functioning individuals (Green & Hummel, 2006) makes them a clear example of higher order effects on perception.

Given the evidence about the abstract nature of the information stored in visual memory and the fact that orientation is part of the spatial information related to an object representation, our first series of experiments aimed at further exploring the nature of this perceptual grouping and whether objects separation would have an effect on it. By combining this paradigm with a paradigm used to explore linguistic factors of perceiving space (Carlson-Radvansky & Radvansky, 1996; Carlson-Radvansky, Covey & Lattanzi, 1999; Carlson-Radvansky & Tang, 2000), we additionally explored the effect of functional interactions at higher levels of post-perceptual processing. We manipulated the locations of various pairs of objects as well as the semantic and functional relationship between them to explore if spatial configurations affect the way people talk about the relationship of the objects in the same way as they affect the same objects' recognition. The results revealed a difference, with the same distance manipulation

affecting linguistic descriptions of spatial relationships between pairs of objects but having no effect in their perceptual grouping.

One of the aims of this thesis is the interpretation of such effects according to a recently growing body of evidence on the interaction between action and perception systems. These systems which were traditionally considered to be two separate disciplines seem to connect, with information from action systems feeding on perceptual systems. Through such an interaction, for example, information about the functionally related objects could lead to their perceptual grouping. A series of experiments have demonstrated effects of action affordances on object perception and their combined results seem to imply pre-attentive effects on object perception independent of the person's intention to act on an object (Riddoch, Humphreys, Edwards, Baker & Wilson, 2002; Tipper, Paul & Hayes, 2006; Symes, Ellis & Tucker, 2007). To further explore the role of functional relationships and action affordances in natural scene viewing, a second series of experiments was designed. These experiments also provided evidence to an old debate about the nature of visual memory and its organisation, adding further evidence for the role of semantic relationship and action affordances in the memory encoding of a scene.

This series of experiments took advantage of the phenomenon of object prioritization during unexpected object onsets or feature changes while viewing real world scenes (Brockmole & Henderson, 2005a). Using a variation of classic change detection paradigms, eye-tracking data were recorded to measure at which point action affordance manipulations would have an effect and to reveal whether object functionality changes can still produce attention capture (quantified as fixation probability to the object of interest), similarly to previously tested semantic changes. Functionality manipulation was achieved by orientation changes of a critical object in the scene, but in a way which constitutes it non functional to the specific context. By comparing action affordance interference during object onsets against interference during object orientation changes we differentiated between pre-attentive and post-selection mechanisms. Our results indicate that although there is no evidence of pre-attentive modulation of object

prioritization, action affordances do have an effect in post-selection mechanisms, with functionally inconsistent objects attracting attention faster and affecting the encoding of an object in the scene representation during memory guided prioritization but not during oculomotor capture. Our results also support the existence of two separate mechanisms for object prioritization.

As a summary, this family of semantic relationships, action affordances and the interplay between action and perception systems has been tested during my PhD research from the very early stages of perception until post perceptual and linguistic accounts of the perceived image. Their role in attention capture and their mediating role to visual memory have also been explored using eye-tracking technology and realistic and rich in information real world scenes. Overall my thesis is oriented towards the aspects that tie all these effects together and further explores the role of action affordances in memory encoding.

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CHAPTER 1

Introduction – Literature Review

INTRODUCTION

Brief Historical Background

The role of action affordances and object functionality on visual perception has been receiving increasing interest over the last decade, following extensive research on other higher level effects of cognition on visual perception, such as semantic knowledge. The origin of the ideas regarding action affordances will be analyzed later in the chapter, but a crude definition of the term “action affordance” relates to the action that an object affords due to its functionality. The term of action affordances is borrowed from Gibson’s theory (1977, 1979) but it is used in a slightly different way in the current thesis to describe the role of motor activations and simulations of the action afforded by an object or the interaction between a pair of objects during perception. Traditionally, research has quite understandably focused on the role of visual perception in action planning and execution, as vision provides motor areas with a major source of perceptual feedback to guide actions. Recent evidence though, has indicated that the relationship between vision and action is not one-sided but is rather interactive (for a review see Tipper, 2004).

Early perception researchers have hypothesized that vision and action systems evolved together to enable successful interactions with the environment (Gibson, 1979; Prinz, 1990). The Gestalt psychologists had already captured this idea in their discussion of the physiognomic character of perception, in which they argued that functional

aspects of an object can be directly perceived without the need for prior object categorization. Gibson (1979) expanded on this notion with his doctrine of action affordances which provided a helpful way to initially characterize and to experimentally explore the way motor systems influence visual perception. Gibson defined action affordances as a function of the overlap between the perceptual features of an object and the action capabilities of a particular actor. The affordance of an object is independent of the observer's ability to perceive it. The affordance is merely an action possibility available in the environment and it does not change as the needs or goals of the actor change. In other words, action affordances are objective as an attribute of the environment, independent of meaning or interpretation, but they are also subjective as an actor is needed as a frame of reference.

The same object, such as a short stick for example, can be used as a walking rod by a midget but not from a tall person. *Direct perception* is defined as adequacy of the information in our sensory receptors without the need for higher-level cognitive processes' mediation between our sensory experience and our perception (Sternberg, 1996). According to Gibson direct perception of object function is achieved when both the physical affordance of the object (e.g. the door can be opened by an actor) and the information in the environment that specifies the affordance (the door is visible, has a handle etc.) are present simultaneously. The information that specifies how the object can be used needs not be explicitly part of the perceptual input (perceived properties), for example a hidden door still affords the same action with a normal door, even when a person cannot see it because physically he can still interact with it in the same way with

any other door. In this case though, direct visual perception of the affordance is obviously not possible. Therefore an object's affordance exists relative to the action capabilities of a particular actor, but the existence of an affordance and the information that specifies the affordance are independent. Although existence of the affordance is independent of the actor's experiences and culture, the ability to perceive the affordance may be dependent on them (McGrenere & Ho, 2000).

Norman, in conflict with Gibson's definition, suggested that an affordance emerges as a relationship that holds between the object and the individual that is acting on the object after the combination of actual and perceived properties (Norman, 1999). This inclusion of perceived properties is the critical difference with Gibson's definition, where affordances exist independently of how the actor perceives them. Norman describes affordances as perceived properties that may or may not actually exist and which provide strong clues to the operations of things and suggest a range of possibilities. According to Norman (1988, p.9) "the term *affordance* refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. [...] Affordances provide strong clues to the operations of things. Plates are for pushing. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instruction needed". Norman's definition seems to combine the affordance and the information that specifies the affordance which are distinct for Gibson, and also in this case there is no actor as a frame of reference for the affordance.

Norman (1988, p. 219) describes that “affordances result from the *mental interpretation* of things, based on our past knowledge and experience applied to our perception of the things about us. My view is somewhat in conflict with the views of many Gibsonian psychologists, but this internal debate within modern psychology is of little relevance here.” The frame of reference for Gibson is the action capabilities of the actor, whereas for Norman it is the mental and perceptual capabilities of the actor. As stated in the previous paragraph, Gibson defines affordances as independent of culture, prior knowledge or expectations of the actor (unlike Norman) but still accepts that the information that specifies the affordance is dependent on the actor's experience and culture (Table 1).

Table 1: Comparison of affordances as defined by Gibson and Norman (table from McGrenere & Ho, 2000).

Gibson's Affordances	Norman's Affordances
<ul style="list-style-type: none"> · Offerings or action possibilities in the environment in relation to the action capabilities of an actor · Independent of the actor's experience, knowledge, culture, or ability to perceive · Existence is binary – an affordance exists or it does not exist 	<ul style="list-style-type: none"> · Perceived properties that may or may not actually exist · Suggestions or clues as to how to use the properties · Can be dependent on the experience, knowledge, or culture of the actor · Can make an action difficult or easy

An example, which would make the difference between the two approaches clear, would be that of a door with no handle and no flat panel. Without prior knowledge of how the door operated, an actor would find it difficult to know the direction of opening. Following Gibson's definition, the fact that the door can be opened by a given actor is sufficient to determine that it has an affordance. (Perhaps the door can be pushed and it

will swing away from the actor or the actor can grasp the door edges and pull.) There does not need to be any visual information specifying the correct direction to the actor for there to be an affordance. According to Norman's use, on the other hand, the affordance would only exist if there was information to specify the possibility for action and the actor had learned how to interpret the information. In this case, there would need to be a door handle that signals the direction of opening to the actor (McGrenere & Ho, 2000).

The discussion about the differences of the definition between Gibson and Norman is relevant for two reasons. Firstly, we need to clarify that the term has been used by various researchers to mean different things. In the current thesis I borrow the Gibsonian term but do not necessarily adhere neither to Gibson's nor Norman's definition. The term of action affordances is used to describe the main action that an object affords based on its functionality and construction. Although for Gibson an object might afford different actions for different actors, many of the stimuli used in our experiments and other relevant experiments are objects like tools, which were constructed for a specific use. For example although a screwdriver might afford a number of actions, when we refer to its action affordance we will focus on its primary functioning of screwing a screw and the relevant motor activations or action simulations of the specific action. Secondly, early suggestions from Gestalt psychologists as well as Gibson that direct perception of action affordances is possible under the correct circumstances, is compatible and even probably formed the basis for the suggestions regarding activation

of action related information in parallel with visual characteristics during object recognition and perception in general.

Finally, it would be useful to point out that the term of “action affordances” in the context of the current thesis incorporates both the input of motoric activations and more generic procedural knowledge. Although it would be ideal to find a way to differentiate the input of each of these processes in the reported influences of action affordances, it is not always easy. In the current thesis no neuroimaging research is included. The use of neuroimaging techniques would allow for testing of the input from motor areas of the brain, but even in this case, the presence of such activations would not necessarily mean that they play a causal role in object recognition and perception in general. According to the relevant literature, motor activations could provide feedback to perceptual systems of the brain and work in parallel, and therefore aid, with the process of visual perception. On the other hand, another aspect of the action affordance related to the functionality of a specific object in a scene or a pair of familiar interacting objects is the semantic-like procedural knowledge. The primary action that an object affords, as discussed in the previous paragraph, is shaped through experience, from the perspective of the observer. The main function of an object might be defined by its construction (for example a screwdriver is manufactured to screw screws), but also the experience of the observer of this interaction throughout his lifetime strengthens the functional connection between the two. This experience includes semantic associations of the fact that using a screwdriver involves screws, in other words the two are normally spatially related, but also includes more detailed information related to their function (e.g. the functional part

of the screwdriver should be attached to the top of the screw) and memory of the actual performance of the action of screwing a screw. Throughout this thesis, both the similarities and differences of this procedural knowledge related to functionality with static semantic knowledge will be discussed, to claim that they are similar but not identical. What is important to clarify at this point, is that action affordances within this thesis do not necessarily imply causal motor system activation over and above semantic-like procedural knowledge.

In contrast to *standard one-way models* which traditionally approach action as the terminal output stage of processing and do not review its impact on preceding processes such as object selection and attention (Sternberg, 1969), *selective action models* have moved towards the suggestion that the selection of action attributes, such as object functionality or action affordances, proceeds in parallel with object attributes such as brightness, contours, colour, orientation etc (Gibson, 1979; Greenwald, 1970; James, 1890; McKay, 1987). Selective processing of specific aspects of an object emerges in a gradual and co-ordinated way, as a result of an initial stage where various components related to the object are simultaneously activated. Instead of treating perception and action as two separate disciplines, these models propose that visual attributes, action affordances, and intentions or goals (Cohen & Huston, 1994; Phaf, van der Heijden & Hudson, 1990; Ward, 1999) are simultaneously processed, and, as such, interact during the act of perception.

Substantial evidence for this position stems from the neuroscience literature. For example, “backward projections” from premotor and frontal regions (typically

associated with initiation and control of action) to both parietal (Matelli et al., 1994) and temporal areas important in the control of visual processing (Jones & Powell, 1970) have been reported in the macaque brain long ago. In fact, over 80% of the connections between cortical regions in the macaque brain appear to be reciprocal (Young, 1995). Brain imaging studies involving humans have also shown the potential involvement of motor areas in the perception of action (“motor perception”). For example, the left inferior parietal lobule, an essential component of the neural network involved in the execution of action, is active during the perception of biomechanically possible actions but not in the case of impossible actions (Stevens, Fonlupt, Shiffrar & Decety, 2000). Action planning and execution systems can be therefore seen as a central component within a distributed processing system (Ward, 1999).

Moreover, based on early neuropsychological data such as the famous case of patient DF, a perception-action distinction in the human visual system has been suggested more than a decade ago. Each of two separate streams – a ventral stream in the occipito-temporal cortex and a dorsal stream in the occipito-parietal cortex – was suggested to play a distinct role during object recognition (Ettlinger, 1990; Milner & Goodale, 1995; Milner, Perrett, Johnston, Benson, et al., 1991; Milner, Perrett, Mishkin & Ungerleider, 1982; Ungerleider & Mishkin, 1982), with the ventral stream dealing with static object features (the “what” stream) and the dorsal stream processing spatial locations and the action related characteristics of objects (the “where” stream). A few years after the isolation of the dorsal and ventral visual streams in the monkey brain (Mishkin & Ungerleider, 1982; Ungerleider & Mishkin, 1982), Neisser noted that the “what versus

where” dichotomy could be neatly mapped on the views of Gibson (1977, 1979) and his main opponents, the advocates of the classical constructivist-inferential approach (Gregory 1993; Helmholtz, 1867; Rock 1983, 1997). The ecological Gibsonian approach of direct perception of action affordances and of the layout of the environment seemed to fit with the functioning of the dorsal system regarding visual control of motor behavior, whereas Helmholtzian constructivist ideas better described the ventral system’s functioning regarding more inferential cognitive processing such as recognition and categorization (this idea was recently further analyzed by Joel Norman - e.g. Norman, 2002).

Although this theory has proven extremely influential, there has been evidence that the “what versus where” distinction is not absolute (Farivar, 2009). There has also been evidence for the commonality of the visual codes on which perception and action are based (Neuman, 1987; Prinz & Hommel, 2002). A single processing stream would provide a more parsimonious explanation, and this “what versus where” distinction could be based on the time course of different processes, with information for action used more rapidly than information for conscious perceptual report (Rosseti & Pisella, 2002). Nevertheless, interactions between the ventral and dorsal visual streams of the human brain (Deubel, Schneider & Paprotta, 1998) could be underlying the functional interactions between action and perception systems.

Recent experiments provide evidence compatible with the predictions stemming from Gibson’s approach regarding automatic action affordance effects on perception. It has been repeatedly demonstrated that within the constraints of particular behavioural goals,

the action that each object affords can be encoded automatically and in parallel with perception (Craighero, Fadiga, Rizzolati & Umiltà, 1999; Ellis & Tucker, 2000; Humphreys & Riddoch, 2007; Klatzky, Fikes & Pellegrino, 1995; Riddoch, Edwards, Humphreys, West & Heafield, 1998; Tucker & Ellis, 1998, 2001) and that competition and object selection take place between these action-based representations (Tipper, 2004). But although vision-to-action processes seem to be rapid and automatic, the effects of action on vision are nevertheless modulated by both excitatory and inhibitory aspects of attention (Diamond, 1990; Houghton et al, 1996; Houghton & Tipper, 1999). Inhibition is useful in constraining potential responses to visual stimuli, thus avoiding chaotic behaviour driven by the dominant action representation of the moment, as information flows continuously into action-based representations (Tipper, Howard & Houghton, 1999). Selective attention can be therefore viewed as competition between visual objects for limited visual processing capacity (Bundesen 1990; Cave & Wolfe, 1990; Duncan, 1984). These points will be further developed in greater depth later in this chapter.

In summary, following the initial ideas regarding action affordances and their contribution in perception, a number of evidence demonstrated cases of parallel analysis of action and visual attributes during recognition. Such evidence support the idea of action affordances influencing perception from the very early stages of visual processing. It was discussed how the Gestalt psychologists' ideas and Gibson's idea of direct perception seem to support modern claims for the automatic nature of motor activations and simulations of interactions when viewing objects that afford an action.

But even from early on, differential definitions of action affordances, such as Norman's, as well as the ideas of the constructivist approach, invite greater caution in inferring the automatic activation of affordance related semantic and procedural information and imply that such influences are rather a result of inferential cognitive processing. Such ideas were mapped on the two visual streams in the brain and modern evidence demonstrated that the boundaries of the two streams are not as absolute as originally thought.

Further evidence regarding automatic influences of action affordances in visual perception as well as evidence questioning the automatic nature of such influences will be presented later in the thesis. Although this evidence suggests that such interactions between perception and action systems seem to be supported in general, the way that action affordances affect visual perception, and how automatic these influences are, are still unclear. Evidence from research of semantic effects on object recognition will be used, because they are more abundant. It will be argued that effects of action affordances are quite similar but also differ at points with semantics effects. Despite their similarity, action affordance effects are not exactly semantic effects. Moreover the evidence presented above for the modulation of action effects on vision by attention, which selectively assigns processing resources to objects during competition or selection, suggest that attention might modulate action affordance effects in the degree that action affordance effects affect object selection. Attention should be taken into account in our research of how action affordances affect visual perception and object recognition.

Thesis Background

To further explore the role of object functionality in perception, the present thesis seeks to obtain converging evidence for the role of action affordances by three different but related areas of research. These three general research areas relate to:

- a) contextual effects in object search and recognition,
- b) the contents of visual memory and their organization, and
- c) the interplay between perception and action mechanisms.

Regarding the first research area, there is ample evidence that, in addition to component features (Biederman, 1987) context also plays a role in object recognition (Biederman, 1972; Boyce & Pollatsek, 1992; Davenport & Potter, 2004; Henderson & Hollingworth, 1999a; Oliva & Torralba, 2006; Hollingworth & Henderson, 2000; Moores, Laiti & Chelazzi, 2003; Palmer, 1975). Context can refer to a number of types of relational information regarding an object and surrounding objects forming a scene. This relational information can be based on low- or high-level cognition effects (see for example the Ebbinghaus - Titchener illusion, Figure 1). One of the simplest instances of context effects in perception is that of brightness contrast; the apparent brightness of a stimulus depends not only on its own luminance but also on that of the surrounding stimulation (“context effect”, 2010; Tsagkaridis, 2006). The same gray square looks whiter against a dark and blacker when placed in a bright background (see for example Adelson’s illusion, Figure 2). In most of the perceptual experiments mentioned above,

the term mainly refers to the *structural context* created by the nature and configuration of various objects comprising a scene or an array.

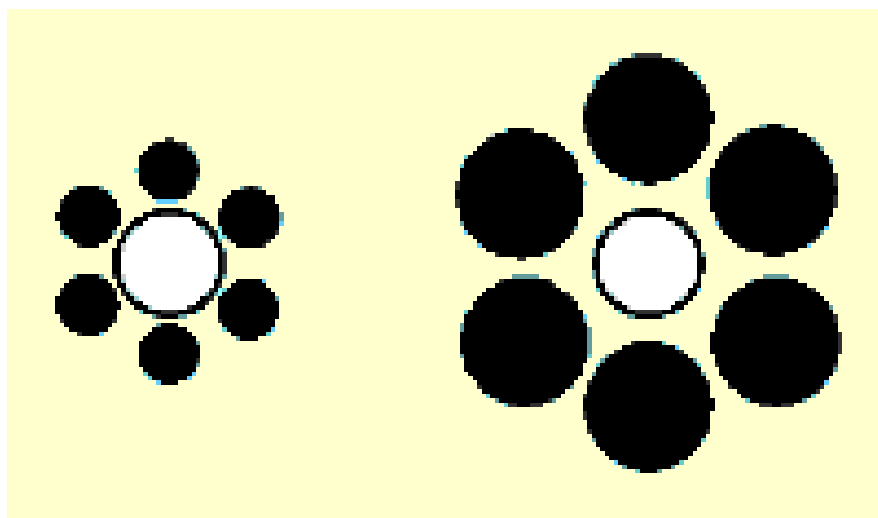


Figure 1: The Ebbinghaus - Titchener illusion.

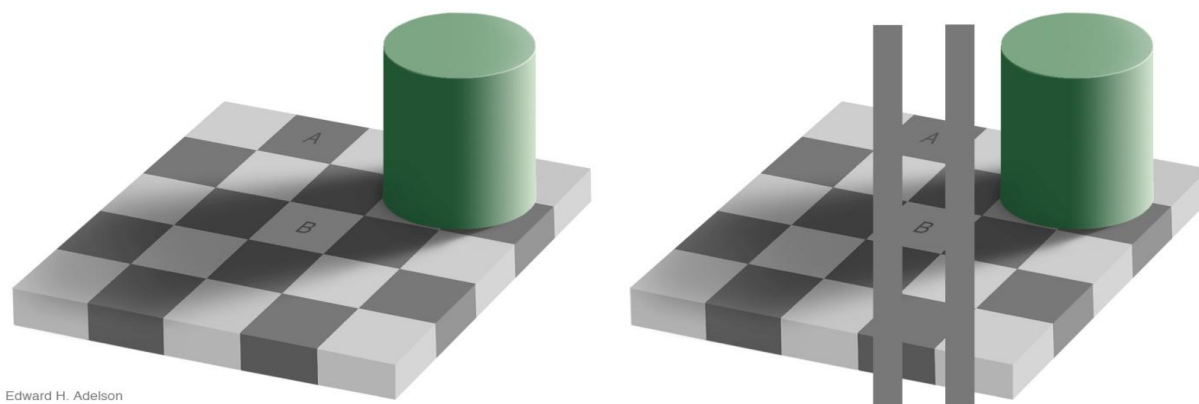


Figure 2: Original Adelson's illusion (left) and proof that tiles A and B are identical (right).
Downloaded from
http://web.mit.edu/persci/people/adelson/images/checkershadow/checkershadow_double_full.jpg

For example, context can impose statistical constraints on the possible locations of specific objects (Ariely, 2001; Chong & Treisman, 2003; Neider & Zelinsky, 2006; Oliva & Torralba, 2001; Torralba, Oliva, Castelhano & Henderson, 2006). Context can also affect expectations concerning the nature of the objects (gist of the scene) that will

be present in a scene (Biederman, 1972, 1981; Davenport & Potter, 2004; Potter, 1975; Torralba, Oliva, Castelhana & Henderson, 2004) and the spatial relations among them (Bar & Ullman, 1996; Biederman, Mezzanotte & Ravinowitz, 1982; Biederman, Ravinowitz, Glass & Stacy, 1974; Brockmole & Henderson, 2006; Chun, 2003; Chun & Jiang, 1998; Henderson, 1992; Jiang, Olson & Chun, 2000; Vidal, Gauchou, Tallon-Baudry & O'Regan, 2005), as demonstrated in object search and recognition experiments.

This rapid extraction of global scene properties (gist) specifically, has been demonstrated to show effects of semantic consistency (Auckland, Cave & Donnelly, 2004; Biederman, Blickle, Teitelbaum & Klatzky, 1988; Boyce & Pollatsek, 1992; Loftus & Mackworth, 1978). The term of semantic consistency refers to the semantic relationship of an object to the rest of the scene. In classic semantic consistency experiments for example, such as the one by Loftus and Mackworth (1978), the presence of a pig would be considered semantically consistent and the eyes would more readily be attracted to it compared to a semantically inconsistent mixer in a farm scene. There is no general agreement on the pre-attentive nature of such effects though (de Graef et al, 1990; Friedman & Liebelt, 1981; Henderson, Weeks & Hollingworth, 1999) and there has been conflicting evidence as to whether scene schemas give rise to expectations (Henderson, 1992; Friedman, 1979) leading to prioritization of consistent objects (Biederman, Mezzanotte & Ravinowitz, 1982; Boyce, Pollatsek & Rayner, 1989) or if inconsistent objects are prioritized (Hollingworth & Henderson, 1998, 2000) based on pop-out effects (Gordon, 2004).

The discussion of semantic consistency effects and their relation to rapid extraction of gist, in other words the global layout of the scene, triggers further questions regarding the second area of the organisation of information in visual memory discussed in this section. Its relevance to our research will be discussed in relation to the combination of the findings of these two areas. The contextual cueing paradigm revealed that the spatial configuration of objects within an array of objects or a scene seems to be important for the organization of information in both Visual Working Memory (VWM) and Long Term Memory (LTM). Performance in detecting changes regarding a specific object feature is poorer when the spatial configuration of an array of objects is changed or when the context of a scene is removed or altered (Brockmole & Henderson, 2006; Chun, 2003; Chun & Jiang, 1998; Jiang, Olson & Chun, 2000; Vidal, Gauchou, Tallon-Baudry & O'Regan, 2005). The role of the context is important, even for tasks that are not directly related to it. For example, Jiang and her colleagues (2000) reported that the disappearance of a non-target item during a blank interval between two successive stimulus frames, leads to a decrease in the ability of the experiment participants to detect a change in the colour of a cued target object. Change of the spatial configuration of the presented array of objects during an interval interferes with feature change detection, but when features change spatial change detection is not affected. This interference is not contingent on verbal coding or increments in baseline noise (Vidal et al, 2005). Information regarding an object is not coded independently, but in relation to the rest of the objects in the scene.

Moreover, research intending to explore the contents of visual memory and its organisation (both short- and long-term memory) has provided evidence that what is encoded is categorical information such as object type as well as abstract spatial relations (Biederman & Cooper, 1991; Carlson-Radvansky & Irwin, 1995; Henderson, 1997; Hochberg, 1978; Hock & Schmelzkopf, 1980; Irwin, 1991; Mandler & Parker, 1976; Vidal, Gauchou, Tallon-Baudry & O'Regan, 2005; Phillips, 1974; Pollatsek, Rayner & Collins, 1984), in addition to specific perceptual details such as exact metric information. The abstract nature of the scene representation does not necessarily mean that configural representations maintain only the abstract spatial layout of occupied locations (Hollingworth, 2004, 2007; Jiang, Olson & Chun, 2000; Standing, Conezio & Haber, 1970), but that information about individual objects bound to those locations (Hollingworth & Henderson, 2002) as well as episodic scene representations such as direct object-to-object association (Davenport, 2007; Hollingworth, 2007) are also included. Schemas, which are developed through experience, are a kind of mental template or framework (Biederman, Mezzanotte & Ravinowitz, 1982; Palmer, 1975) which we can potentially use to facilitate encoding and retention of spatial relations among objects. Such templates include information about object functionality, and the knowledge of their normal spatial configuration with respect to other objects might even prevail over perceptual descriptive details, as long as no real-world knowledge violation is present (Brewer and Treyns, 1981; Friedman, 1979; Intraub, 1997; Mandler & Ritchey, 1977; Pedzek, Whetstone, Reynolds Askari & Dougherty, 1989).

For example, in an experiment where participants were left in an office to supposedly wait for the experimenter, and their memory about the objects in that office was unexpectedly tested, participants showed a strong tendency to recall objects consistent with the typical “office schema”. Most of them recalled objects that you typically expect to find in an office (such as a desk or chair), but not the ones that were less typical (such as a picnic basket); many of them even recalled schema-relevant items, such as books, that were not present in the office (Brewer and Treyens, 1981). The specific experiment though has been criticized based on the fact that there was no control over guessing, so the evidence for this memory normalisation might have been generated by a bias to guess that semantically consistent objects had been present in the scene (Hollingworth, 2009). For example, other studies which controlled for guessing found evidence for better memory for semantically inconsistent objects in scenes (Friedman, 1979; Hollingworth & Henderson, 1998, 2000, 2003; Pedzek, Whetstone, Reynolds, Askari & Dougherty, 1989). Nevertheless, better recognition has been demonstrated for a change in the spatial relationship between two objects in complex organized pictures in comparison to unorganized arrays of the same objects (Handler and Stein 1974; Mandler & Parker, 1976). Such effects demonstrate that the accuracy of object recognition may depend primarily (or at least at a significant extend) on figurative memory, which in the context of the present experiments would be defined as the input of expectations based on relevant schemata in the memory representation of a scene and the functionality of the objects in it.

By combining the well known gist effects and the role of semantic consistency in attracting fixations and the modulation of object recognition on one hand, and the relational (Hollingworth, 2006) and abstract nature of the information retained in VWM and LTM on the other hand, it seems reasonable to suggest that local characteristics such as the functional relationship between objects can potentially affect perception (see for example Green & Hummel, 2004). Due to the abstract nature of the information encoded, it is reasonable to assume that these local relationships are not based on precise metric information or object orientations per se, but they are rather encoded in terms of relevance to the specific object's schemas. For example the orientation of an object might be encoded based on whether it violates the expected orientation due to a stored template (schema) of the typical orientation that allows for its normal functional use (such as a glass with its open side up, rather than upside-down) or the position of another object in relation to that object in cases where the two are normally paired together to form a common action (such as a jug with its functional end facing towards the glass to allow for the pouring action, rather than away from it).

A third line of more recent research concerning the relatedness of perception and action indicates a close relationship between action affordances among objects that can interact or that afford a specific action, and their perception. In general, effects of action on visual perception have been demonstrated in cases of prehension (reaching and grasping) modulating attention (Simon, 1969; Stürmer, Ascherleben & Prinz, 2000), in cases of target search and identification processes in normal (Bekkering & Neggers, 2002; Deubel, Schneider & Paprotta, 1998; Green & Hummel, 2006; Müsseler &

Hummel, 1997) and clinical populations (Humphreys & Riddoch, 2001; Riddoch et al., 2003), and in cases of distracter interference and selection mechanisms (Eriksen & Eriksen, 1974; Stroop, 1935). Additionally there has been evidence that even unconscious information can prime motor responses (Schmidt, 2002).

Automatic encoding of motor information specifically has been demonstrated both in studies of neglect patients (Humphreys & Riddoch, 2001, 2007; Riddoch et al, 2003, 2006) as well as healthy controls (Symes, Ellis & Tucker, 2007; Tucker & Ellis, 1998). Interactions between object function and identity have been reported in visual object identification research with neuropsychological populations (Harman, Humphrey & Goodale, 1999). It has been demonstrated that action affordances can reduce visual neglect by bypassing the competition for attentional processing through the perceptual grouping of functionally related pairs of objects (Riddoch, Humphreys, Edwards, Baker & Wilson, 2003; Humphreys & Riddoch, 2001; Humphreys, Riddoch, Forti & Ackroyd, 2004). Similarly action affordances were reported to influence visual search (Bekkering & Neggers, 2002) and visual recognition (Green & Hummel, 2006; Tucker & Ellis, 2004). These seminal papers will be analyzed in greater detail in the following sections.

A similar inseparable link between perception and action is central in Rizzolatti's "Pre-motor Theory of Attention" and the research on mirror neurons (di Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Riggio, Dascola & Umiltà, 1987). Although the mirror neuron theory originated from macaque brain research, similar networks of neurons in humans were found to be activated during observation of the actions of other people (Rizzolatti &

Craigero, 2004). Like many other researchers (Broadbent, 1958; Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Doshier & Blaser, 1995; LaBerge & Brown, 1989; Peterson, Kramer & Irwin, 2004), Rizzolatti has noted that preparation of eye-movements automatically involves shifts of attention, and that spatial attention allocation is important for object recognition. In his theory, spatial attention is driven by the exact same mechanisms responsible for movement in space.

The link between action and perception is so strong, that it can be demonstrated in experimental situations of “action blindness”, where execution of lateralised hand movements interferes with the identification (Müsseler and Hommel, 1997a) and detection (Müsseler and Hommel, 1997b) of items semantically related to the response. For example in the task of speeded identification of a masked left or right pointing arrow, presented shortly before executing an already prepared left or right key press response, the probability of identification was decreased when the arrow orientation matched the prepared response (Müsseler and Hommel, 1997a). The researchers’ interpretation of such phenomena is that preparation for action may bind some kind of global type representation, common with the representation needed for spatial perception, so that this representation becomes subsequently unavailable for perception of the visual stimulus. This effect is analogous to repetition blindness (Kanwisher, 1987) which has been attributed to difficulties in binding multiple tokens (defined as different instances of an object, i.e. a number of pears in a bowl) to a single type (i.e. object type = pear). Such findings have led Hommel and his colleagues to propose the “Theory of Event Coding” (TEC) which claims that there is a common representational medium

between visual perception and action systems (Hommel, Musseler & Aschersleben, 2001).

Experiments using more subtle measures of action affordance effects (Symes, Ellis & Tucker, 2007) reported similar findings as well. Action affordance compatibility effects in these experiments were claimed to be based on associated actions generated spontaneously by an active object representation. Such effects are also independent of whether the object is concurrently visible at the time of response and of the form of the stimulus - be it an image or a word naming the object (Tucker & Ellis, 2004). Although not necessarily based on the same mechanisms, mirror cell activation has also been reported to be independent of the visibility of an action (Umiltà, Kohler, Gallese, Fogassi, Fadiga, Keysers & Rizzolatti, 2001) and can even be triggered by the sound of an action performed without the action being visible (Kohler, Keysers, Umiltà, Fogassi, Gallese & Rizzolatti, 2002) .

On the other hand, experiments such as comparison of pointing at an object and grasping (Bekkering & Neggers, 2002; Tucker & Ellis, 2004) also indicate the automatic activation of affordance compatibility effects, but only in cases involving actual actions or intentions to perform an action. These experiments took advantage of the fact that grasping is more prone to effects of action affordances than pointing, because of the required activation of action-relevant features of an object (such as orientation, size and shape). The enhancement of the visual processing of action-relevant features by an action intention such as grasping was also demonstrated by fewer saccades to incorrectly oriented (but not incorrectly coloured) distractor objects in an experiment conducted by

Bekkering and Neggers (2002), supporting the view that visual attention can be best understood as a selection-for-action mechanism (Deubel, Schneider, Paprota, 1998; Schiegg, Deubel & Schneider, 2003).

As a conclusion, a growing body of evidence implies that it is possible to detect behavioural effects of action on object recognition. It seems that even the mere observation of an object with the intention of categorising or understanding it is sufficient to activate motoric representations related to its functionality and simulate the actual handling of that object by the observer (Chao & Martin, 2000; Gerlach, Law, Gade & Paulson, 2002; Grafton Fadiga, Arbib & Rizzolatti, 1997; Grèzes & Decety, 2002; Grèzes, Tucker, Armony, Ellis & Passingham, 2003; Martin, Wiggs, Ungerleider & Haxby, 1996; Prinz & Hommel, 2002). But experiments like the ones mentioned above, where pointing at an object is compared with grasping, question the absolute automaticity of the activation of such representations, or at least whether such representations will have a behavioural impact when no action-related information is immediately relevant to the observer's task.

Based on such evidence, the aim of this thesis was to test how automatic the nature of action affordance influences on visual perception is. To do this we tried to break down the different factors that may contribute in action affordance influences. For example we needed to differentiate between pre-attentive and post-selection influences of action affordances and object functionality in the process of object perception and recognition. The role of attention was also deemed important for the influence of action affordances in object selection and guidance of eye-movements.

The rest of this chapter reviews the main evidence of action affordance effects on perception. These influences can be coarsely categorized in experiments exploring functional interactions of related objects and experiments exploring action affordance influences of single objects. Relevant findings will be discussed in relation to each category separately to detect different factors that affect the reported influences in the action affordance and object functionality literature. Moreover, analysis of action affordance influences in this thesis will not be confined in pre-attentive effects but will be explored at different levels of visual processing. Functional interaction influences on pairs of objects have been reported both in perception and language research for example, and comparison of these two lines of research will be helpful in pinpointing the way these action affordances affect object recognition and post-recognition spatial descriptions. Finally, after reviewing action affordance effects in the case of objects' interaction, we will try to analyze action affordances at a more basic level of single objects and again separately explore these effects at different levels of processing, from pre-attentive to post-selection effects.

Action Relations between Objects – Perceptual Grouping

In a study by Riddoch and her colleagues (2003) the neuropsychological phenomenon of extinction in human patients was used to explore how object selection can be influenced by action relations between object pairs. Patients who demonstrate extinction have the ability to detect single stimuli presented on the contralesional side of space, but they fail to detect the same stimulus under bilateral presentation conditions, where

another stimulus is concurrently presented in the ipsilesional side of space; therefore extinction cannot be attributed to any deficit in detecting the contralesional event on its own (Critchley, 1953; Humphreys & Riddoch, 2003; Ward, 1999). Patients' performance in detecting the objects briefly presented to them was found to be better for objects that were positioned spatially so that they could be used together for a common action (for example a pair of a hammer with its functional end facing a nail), relative to objects that were positioned inappropriately for their combined use (for example a hammer facing away from a nail). Contrasting this performance with semantic word associations proved that the action relation was critical; performance for pictures did not improve if the items were only verbally associated. On the other hand, semantic associations were useful with lexical stimuli, possibly reflecting priming between lexical entries. Effects of action relations were reported even on trials where only one object could be reported and, based on this result, the researchers suggested coding of 'action' units for selection to be implicit (Riddoch, Humphreys, Edwards, Baker & Wilson, 2003).

The behaviour of visual extinction that neglect patients demonstrate, mostly associated with unilateral damage to the patient's posterior parietal lobes (Karnath, 1988), has been described as a chronic limitation in visual selection. Activation in the primary visual cortex of patients under unilateral and bilateral conditions indicated that this deficit is not perceptual in nature (Rees, Wojciulik, Clarke, Husain, Frith & Driver, 2000) but can be rather attributed to a selection bias, caused by lesions in the appropriate parietal lobe network responsible for controlling spatial attention (Desimone & Duncan,

1995). In a sense it has been suggested that visual extinction is a spatially specific bias, an extension of a normal attentional limitation (Baylis, Driver & Rafal 1993; Kaplan, Verfaellie, De Witt & Caplan, 1990; Ward & Goodrich, 1996; Ward, Goodrich & Driver, 1994) uncovered by the parietal damage of neglect patients which reduces the influence of spatial attention on selection (Humphreys & Riddoch, 2003).

The explanation for the reduction of visual neglect in the case of interacting configurations of familiar object pairs offered by Humphreys and Riddoch (2001, 2007) is that perceptual grouping facilitates object selection and bypasses the competition for attention between the two objects (see also Ward, Goodrich, & Driver, 1994).. Unilateral parietal damage in neglect patients seems to be weakening the competitive strength of stimuli in the contralesional visual field, in comparison to the ipsilesional visual field. When there is only one potential target contralesionally, there is no problem for it to engage limited-capacity processes even though it is weaker than normal, but when another stronger potential target is present in the ipsilesional side, the weaker contralesional potential target is extinguished (Desimone & Duncan, 1995; Humphreys, Romani, Olson, Riddoch & Duncan, 1994; Ward, 1999; Ward & Goodrich, 1996).

However, it has already been demonstrated that when parts of an image are grouped, they can be selected together as one object (Duncan, 1984; Duncan & Humphreys, 1989; Egly, Driver & Rafal, 1994; Gilchrist, Humphreys & Riddoch, 1996; Humphreys & Riddoch, 2003) and so the objects do not compete for attention (Conci et al, 2009; Duncan et al, 1997; Kinsbourne, 1993). Space-based attention is nevertheless implicitly coupled with object-based attention and is therefore drawn to the location occupied by

the winner of object-based competition for selection (Farah, Wallace & Vecera, 1993; Humphreys & Riddoch, 1993, 2003; Vecera & Farah, 1994). Non-spatial extinction can also be attributed in object-based selection operating independently of the spatial selection system (Humphreys, Romani, Olson, Riddoch & Duncan, 1994).

The role of grouping of separate elements in one perceptual form has been studied since the early 20th century by Gestalt psychologists, who extensively explored how elements are grouped in a bottom-up manner using visual cues in an image (e.g. Wertheimer, 1912). For the Gestalt researchers an object is defined as a stimulus whose parts conform to the rules of grouping, binding the elements of this stimulus in a single entity. Although this process of grouping is seemingly effortless and automatic from the perspective of the observer, it is nevertheless an active process from the perspective of the visual system. In that sense these early Gestalt ideas are compatible with recent theories of object identification which focus on the active binding of various pieces of information related to an object in a single form, such as the “Object File Feature Integration Theory” by Treisman and Gelade (1980). This idea also introduces the role of the familiarity of the stimulus in influencing what we code as an object, even when there are no Gestalt cues present to produce better grouping for parts of familiar over unfamiliar objects (Humphreys & Riddoch, 2007).









In addition to grouping based on lower level factors such as collinearity (Gillchrist, Humphreys & Riddoch, 1996; Mattingley, Davis & Driver, 1997), connectedness (Humphreys & Riddoch, 1993; Humphreys, 1998; Palmer & Rock, 1994), common shape, common contrast polarity (Gillchrist, Humphreys & Riddoch, 1996; Humphreys,

1998), common region (Humphreys, 1998) and whether elements are part of a known shape (Kumada & Humphreys, 2001; Ward, Goodrich & Driver, 1994), co-occurrence of various components habituates the visual system and leads to forming schemata and expectations at higher conceptual levels too, such as in the case of gist – semantics effects on object recognition, rapid assimilation of objects into scenes (Biederman, 1982; Henderson & Hollingworth, 1999) and context effects on object detection (Chun & Jiang, 1998).

The visual system becomes sensitive to perceptual units as a function of whether the elements making up these units occur together, which could be for example achieved by some kind of Hebbian learning (Hebb, 1949) increasing interconnectivity between neurons responding to related elements. The bibliography on the role of action affordances though implies that associative co-occurrence is not sufficient, because our learning of visual units is contingent on an event-related parsing of world, which itself is determined by causal action between objects. Contextual knowledge therefore seems to be sensitive to action between objects, as opposed to word associations which are dependent on lexical knowledge but are not affected by potential interactions between objects (Riddoch et al, 2003).

A recent experiment by Green and Hummel (2006) has demonstrated findings similar to the ones provided by the extinction literature and studies of clinical neglect patients, within a normal population. Their study demonstrated better performance in an object recognition task for familiar groupings of interacting objects, as compared to both unfamiliar groupings and non-interacting configurations. Their experiment presented

two objects in quick succession for a very brief time (50 msec for each object). The first object, presented in the centre of the screen (i.e. at fixation), was an asymmetrical object whose orientation was critical for establishing a potential interaction with the second object. The second object was displaced either to the left or to the right. The semantic and functional relationship between the objects was manipulated (see the figure below, taken from Green & Hummel, 2006). Examples of semantically related objects include a lock and key or a water pitcher and glass. An example of a semantically unrelated pair was a hammer and flower. Objects were considered functionally related if they were depicted in an interactive way. The potential for such an interaction was based on the orientation of the first object, and specifically its functional end in relation to the second object. For example, a key oriented to fit into a lock or a hammer oriented to hit a flower.

		Related		Unrelated	
		Interacting	Not Interacting	Interacting	Not Interacting
Positive					
Negative					

The label is “glass” in these examples.

Figure 1. Examples of stimuli in each condition. Here, the label is “glass.” Distractors could be related (R) or unrelated (U) to the label and could be oriented to interact (I) or not interact (N) with the target (the target matched the label on positive trials [top row] and did not match the label on negative trials [bottom row]). The

The participant's task was to simply report whether a pre-determined object was presented in the short 2-object sequence. When the target was present, it was always the second of the two objects. Therefore, the first object was irrelevant to the identification task. However, Green and Hummel demonstrated that both the semantic and functional relationship between the items influenced target detection. Functionally related configurations benefitted target recognition in semantically related pairs of objects, whereas the opposite pattern was found for pairs of semantically unrelated objects. For example, a jug with its functional end facing towards a glass would facilitate identification of the glass. The same object with its functional end towards a lock on the other hand, not only failed to benefit perception, but also reduced accuracy in the detection of the lock.

Similarly with the result of Humphreys and Riddoch's experiment, Green and Hummel's (2006) explanation for the advantage in target detection, in cases where the target object to be recognized was forming a functional pair with the distractor object, was that the two objects are in this case perceptually grouped (Green & Hummel, 2004, 2006), therefore facilitating recognition. Green and Hummel tested the hypothesis that their result is based on the perceptual grouping of the two objects rather than post-perceptual schema effects by significantly increasing the SOA in a second experiment, which, based on previous research, would be sufficient to hinder perceptual integration (Brockmole, Wang & Irwin, 2002). Their results verified that indeed with a 250 msec SOA there was no advantage for familiar interacting groupings, since the two objects could not be perceptually grouped. Moreover with further experiments they ruled out the

possibility that their findings were based on either the attentional cueing by the functional end of the object or by expectations about the identity and configuration of the objects, by reversing the order of the two objects and moving the target stimulus after the objects' presentation respectively.

Stimuli that are part of a common movement in a scene, such as two objects that are picked-up and used together, tend both to be spatially close together and to be linked within the same temporal event. Perceptual objects above the level of single physical entities have been hypothesized to be formed when the physical entities are part of a common action, with these action relations consequently constraining the formation of a higher-level perceptual unit (Humphreys & Riddoch, 2007). Similar effects of high level grouping have also been reported in cases where extinction is by-passed, e.g. when patients are presented with letters which form a word; this was found to even over-ride effects of bottom-up grouping (Kumada & Humphreys, 2001) and could be based on word-level mental representations selectively activated by the presence of familiar groupings of letters in words (Johnston, 1981; Johnston & McClelland, 1980; McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). An interesting finding in the Green and Hummel experiment was that this facilitation was confined in pairings of objects that are normally used together, both semantically and functionally. There was not an adequate explanation though why a similar configuration, positioning the two objects in a functional interaction, deteriorated performance in the case of unfamiliar groupings of objects.

Humphreys and Riddoch's (2001) patient was one of the first reports of a case of unilateral visual neglect where functional information seemed to facilitate recognition of a target object. The same functional information though did not speed up the patient's search. Functional information aided the task of object recognition, but did not have an effect on object localisation (Humphreys & Riddoch, 2003). At the same time, there is abundant evidence that visual representations stored over seconds of scene viewing are not sensory (or iconic) in nature (for a review see Irwin, 1992). Iconic memories decay within a few hundred milliseconds after a stimulus event (Averbach & Coriell, 1961; Di Lollo, 1980; Irwin & Yeomans, 1986; Sperling, 1960) and are not integrated across disruptions such as saccadic eye movements (Grimes, 1996; Henderson & Hollingworth, 2003; Irwin, 1991). Similarly, spatial relations encoded by the perceptual system do not consist of precise metric information (Irwin, 1991; Phillips, 1974), but are rather relational and these relations both within objects (Biederman, 1987; Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996; Rosielle & Cooper, 2001) and scenes (Mandler & Parker, 1976; Mandler & Ritchey, 1977) are encoded quantitatively. Information such as object orientation (Van Eccelpoel, Germeys, De Graef & Verfaillie, 2008; Henderson & Hollingworth, 1999b, 2003a; Henderson & Siefert, 1999, 2001) and structural relationships between objects (Hollingworth, 2007) or object parts (Carlson-Radvansky, 1999; Carlson-Radvansky & Irwin, 1995) has been specifically found to be part of such representations.

This evidence has motivated further research on the mechanisms responsible for the perceptual grouping of semantically related and functionally interacting objects as part

of the aim of this thesis. Specifically, given the ample evidence about the relational coding of object information with regard to other objects in the scene we were interested to check whether this perceptual grouping is contingent on local characteristics of the visual display or whether it can be done at higher levels of abstraction. To get an indication of whether such a perceptual grouping can have ecological validity, with measurable effects at more realistic and more visually rich contexts as compared to simple experimental designs, we needed to verify that this effect is not due to a specific positioning of the objects in a visual display or that it is not too sensitive to manipulations such as the distance between the two objects. We used an adaptation of the Green and Hummel (2006) paradigm to further explore the mechanism of perceptual grouping due to semantics and action affordance manipulations.

Functional Interactions between Objects in Language Research

The issue of spatial configuration, functional interactions between objects and the interaction of the description of spatial relations (language) with perception have also been extensively studied in another area of linguistic research (Jackendoff & Landau, 1991; Landau & Jackendoff, 1993; Levelt, 1982, 1984; Talmy, 1983). Object function specifically has been shown to play a crucial role in object categorisation and naming (Landau, Smith & Jones, 1998; Madole & Cohen, 1995; Madole, Oakes & Cohen, 1993; Miller & Johnson-Laird, 1976; Rosch, Mervis, Gray, Johnson & Boyes-Braem, 1976). Functional parts of objects have been demonstrated to be particularly salient in speeded categorization tasks (Lin & Murphy, 1997). At a theoretical level it has been suggested

that the function of an object might be helpful in determining the relevant parts in a scene during schematization (Herskovits, 1986, 1998).

The relevant literature explores functional influences on spatial relations and their descriptions and seems to address very similar questions on functional interaction effects, though at later levels of object processing compared to the perceptual experiments (Carlson & Covey, 2005; Carlson-Radvansky, Covey & Lattanzi, 1999; Carlson-Radvansky & Tang, 2000; Carlson & Kenny, 2006; Carlson-Radvansky & Radvansky, 1996). Traditionally, spatial terms like “above” or “below” which specify the location of an object (located object) with respect to the known location of another (reference) object (Beun & Cremers, 1998; Levelt, 1996; Talmy, 1983) have been suggested to be based on the degree to which the centres of mass between the two objects are aligned (Gapp, 1995; Regier, 1996; Regier & Carlson-Radvansky, 1999; Schirra, 1990). Recent evidence though suggests that centre of mass effects are not absolute and use of such spatial terms can be modulated by object functionality and characteristics (Carlson-Radvansky, Covey & Lattanzi, 1999; Carlson-Radvansky & Radvansky, 1996; Carlson-Radvansky & Tang, 2000; Coventry & Garrod, 2004).

When we want to locate a target object (located object) in relation to another object (reference object) following such spatial descriptions, reference frames are imposed on reference objects and define the space in which to search for a located object (Carlson-Radvansky & Logan, 1997; Carlson-Radvansky & Irwin, 1994; Garnham, 1989; Herskovits, 1986; Levelt, 1984; Logan & Sadler, 1996). A reference frame is defined as a set of three coordinate orthogonal axes whose intersection point is the origin from

where search will start (Miller & Johnson-Laird, 1976). Various factors can influence these axes' orientation, leading to different kinds of reference frames. For example in viewer-centred reference frames the axes are aligned in accordance with the retinotopic, head-centric, or body-centric orientation of the viewer, whereas in object-centred reference frames, the axes are oriented with respect to the intrinsically defined sides of an object.

Early research on spatial description usage revealed a preference for intrinsic descriptions (or object-centred reference frames) in the presence of functional relationships, whereas deictic-extrinsic descriptions (or viewer-centred reference frames) were preferred in the case of the absence of a functional relationship (Carlson-Radvansky & Radvansky, 1996; Fillmore, 1975; Miller & Johnson-Laird, 1976). In a task of positioning an object over another reference object for example, the manipulated object was spatially attracted towards the functional end of the reference object and this effect was bigger for familiar rather than unfamiliar object pairings. Also, both actual positioning and acceptability ratings of spatial descriptions were biased towards functionally interacting familiar pairs of objects (Carlson-Radvansky, Covey & Lattanzi, 1996).

For example, when a person is asked to put a painting below a clock on the wall, or reversely hear that the painting is situated below the clock, he/she will imagine that the centre of mass of the two objects is aligned. On the other hand, when one of the objects has a functional end and the two objects are semantically related and can be combined in a meaningful interaction, such an alignment will be based on the object's functional end;

on being asked to place or on hearing that a toothbrush is below the toothpaste for example, a person would imagine the end with the brush, rather than the centre of mass of the toothbrush (which would be situated between the brush and the handle), to be situated below the opening of the toothpaste.

These linguistic experiments relate to the discussion of the perceptual experiments presented above and allow for further testing of the effects of action affordances at later stages of object recognition and visual processing. Comparison of their findings with pre-attentive effects on perception could prove interesting in determining how early in the perceptual processing factors that have been found to affect spatial language take place. By expanding our adaptation of the perceptual paradigm (Green & Hummel, 2006) which intended to explore the mechanisms and the nature of perceptual grouping, we could explore how the same manipulations would affect spatial language at later levels of processing of a visual display and directly compare these results with object recognition effects.

Evidence for the Role of Action Affordances in Object

Prioritization and the Role of Attention

So far I have reviewed the evidence outlining the role of action and motor systems during visual perception and post-perceptual spatial descriptions. Claims for a common evolution of vision and action systems were presented, along with theories which focus on the parallel processing of action and object attributes. Such theories question the

notion of action as the terminal output stage of processing. Neural mechanisms which could possibly support such action-perception interactions were also reviewed. The notion of action affordances and their role in object selection and resolution of competition was reviewed based on modern neuropsychological findings. A similar link between perception and action in the case of the “Pre-motor Theory of Attention” and mirror neuron research was presented, along with theories that suggest a common representational medium between visual perception and action systems. Finally the findings from research on perceptual effects of action affordances were compared with post-perceptual effects in spatial language use during the description of objects’ interaction. Evidence is not conclusive though about how automatic these action-representations are at a purely perceptual level, for example in real-world scene perception where no action is immediately intended and where there is a huge amount of information and a variety of objects with different action affordances.

Although recently there has been evidence for the perceptual grouping of familiar interacting objects (Green & Hummel, 2006; Humphreys & Riddoch, 2007) indicating measurable effects of action affordances on visual perception, these experiments mostly used artificial designs with abstract representations of objects presented at quite sparse backgrounds. They also used pairs of objects and tasks that primed attention to their functional relationship. Their results were therefore based on a combination of perceptual grouping, attention modulation and physical affordances. In the present thesis I was interested to apply such findings in a new paradigm, using different measurable variables to test evidence of action effects on perception of a single object in more

realistic situations. In addition to reaction times, eye-movement analysis could provide greater flexibility in breaking down the contribution of the different factors mentioned above in the action affordance effects demonstrated, as well as explicitly compare pre-attentive with post-attentive effects of action affordance influences on perception.

Eye movements are an excellent measure of the deployment of attention because these two behaviours are highly coincident (Deubel & Schneider, 1996; Henderson & Ferreira, 2004; Henderson, Pollatsek & Rayner, 1989; Shepard, Findlay & Hockey, 1986). The way people move their eyes during active scanning of the world around them has been receiving greater interest from vision researchers, due to the fast progress of eye-tracking technology. Because the deployment of attention is critical in modulating the effects of action affordances on visual perception, recording of eye-movements can provide an accurate measurement of the effects of action mechanisms on visual perception systems and behaviour.

There has been extensive research on the factors themselves that guide the deployment of eye-movements during scene viewing (Henderson, 2003, 2007). These factors can be broadly characterized as volitional - task relevant factors (Antes, 1974; Buswell, 1935; Gibson, 1996; Hayhoe, Shrivastava, Mruczek & Pelz, 2003; Henderson, Brockmole, Castelhana & Mack, 2007; Henderson & Hollingworth, 1998a; Henderson, Weeks & Hollingworth, 1999; Macworth & Morandi, 1967; Land, Mennie & Rusted, 1999; Torralba, Oliva, Castelhana & Henderson, 2006; Yarbus, 1967) or automatic - low level factors such as visual saliency, colour (Matsukura, Brockmole & Henderson 2009), intensity, orientation (Itty & Koch, 2000; Koch & Ullman, 1985; Parkhurst, Law

& Niebur, 2002), contour junctions, termination of edges, stereo disparity and shading (Koch & Ullman, 1985). Even in ongoing natural behaviour it has been demonstrated that cognitive goals play a critical role in the distribution of gaze (Hayhoe & Ballard, 2005; Land, 2004) and the more specific the visuomotor task to be executed the more stereotyped and tightly linked are fixations to the actions necessary for the performance of the task (Hayhoe, Shrivastana, Mruczek & Pelz, 2003; Land & Furneaux, 1997; Land & Lee, 1994; Land, Mennie & Rusted, 1999; Patla & Vickers, 1997; Pelz & Canosa, 2001; Turano, Geruschat & Baker, 2003).

In general, visually or semantically salient objects have the ability to capture attention even when they are not relevant to one's task (Brockmole & Henderson, 2005a) and can even interrupt performance of a goal-directed behaviour (Belopolsky, Theeuwes & Kramer, 2005; Brockmole & Henderson, 2005a; Donk & Theeuwes, 2003). Such *attention capture* can be caused by distinctive characteristics within a visual display, such as abrupt onsets (Boot, Krammer & Peterson, 2005; Irwin, Colcombe, Kramer & Hahn, 2000; Theeuwes, Kramer, Hahn & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin & Zelinski, 1999; Yantis & Jonides, 1984) or offsets (Brockmole & Henderson, 2005b; Theeuwes, 1991), unique luminance, colour (Irwin et al, 2000; Matsukura, Brockmole & Henderson, 2009) or shape (Theeuwes, 1994) and motion (Chastain, Cheal & Kuskova, 2002; Franconeri & Simons, 2003; Jonides & Yantis, 1988; Theeuwes, 1994).

Similarly, in relevant eye-tracking experiments from Brockmole and Henderson (2005a, 2005b, 2008), instances of attentional prioritization were demonstrated to be driven either by top-down factors (memory guided prioritization), or by visual saliency

related characteristics of a critical object or a part of a real-world scene (oculomotor capture). Behaviours similar to oculomotor capture have in addition been demonstrated in experiments with manual responses (Hunt, von Mühlenen & Kongstone, 2007; Ludwig & Gilchrist, 2002), adding further evidence to the relationship between perceptual and motor systems and the theories of a common representational medium of perception and action (Hommel, Musseler & Aschersleben, 2001).

Oculomotor capture has been widely studied in experiments where various objects appeared suddenly in the display from very artificial sparse displays (Irwin, Colcombe, Kramer & Hahn, 2000; Theeuwes, Kramer, Hahn & Irwin, 1998) to real-world scenes (Brockmole & Henderson, 2005a, 2005b, 2008; Matsukura, Brockmole & Henderson, 2009). Brockmole and Henderson (2005a) define oculomotor capture as “the disruption of the top-down direction of eyes by the abrupt appearance of a new but task irrelevant object”. Later experiments have demonstrated that not only appearance but also disappearance (Brockmole & Henderson, 2005b) as well as feature changes such as the colour of objects in real world scenes (Matsukura, Brockmole & Henderson, 2009) can cause prioritization. More importantly it was hypothesized that attentional prioritization can be supported by two different mechanisms, either based on oculomotor capture in the cases where, simultaneously with the change or onset, there was a transient motion signal present, or based on memory guided prioritization in the case of absence of transient motion signals (Brockmole & Henderson, 2005a, 2008; Karacan & Hayhoe, 2008).

In Brockmole and Henderson's seminal experiments (2005a, 2005b), saccadic suppression was utilised to achieve changes unaccompanied by a transient signal. Visual encoding is suppressed during each brief saccadic eye movement (Matin, 1974), so having changes in the display happen while the eyes are still moving during a saccade, instead of happening within a fixation, accomplishes masking of the transient signal. In such experiments the propensity of the eyes to be directed to the critical object once it had appeared (Theeuwes, Kramer, Hahn & Irwin, 1998) or changed (Matsukura, Brockmole & Henderson, 2009) was utilized as a measure of attentional prioritization.

Previous work from Brockmole and Henderson compared attentional prioritization between fixation and saccade changes using real-world scenes. The efficacy of oculomotor capture in grabbing attention has been studied extensively in previous experiments, even with simpler displays of visual arrays of geometric shapes (Boot et al, 2005; Irwin et al, 2000; Theeuwes et al, 1999), and showed oculomotor capture to happen at approximately 50% of the trials used. Fixations on onsets though are usually atypically brief, maybe implying that a saccade to the target was already programmed but was interrupted by the onset before it was executed. Participants themselves are often unaware of this deviation (Theeuwes et al, 1998) and it makes no difference if the participants' task is to spot the change/onset or study the scene for a memory test (Brockmole & Henderson, 2005a). Attention capture during saccade changes on the other hand has not been extensively studied in displays with simple arrays of stimuli.

These simple arrays of objects used in traditional research on attention capture are qualitatively different than real-world scenes and this is one of the reasons that originally

led to the recent experiments from Brockmole and his colleagues (2005a, 2005b, 2008, 2009). The real world has of course far more visual complexity and semantic coherence than such simple arrays (Henderson & Ferreira, 2004) and usually there are no single unique items among homogenous collections of objects (Brockmole & Henderson, 2008). Moreover the real world allows expectations – or schemas to help guide our attention and eye-movements, so such stimuli are much more realistic and appropriate to study higher order effects on perception such as the role of memory, as in the case of memory guided prioritization. Finally feature changes of objects (such as colour or action affordances) have a less abstract nature when they are situated in real-world scenes as compared to sparse environments, such as a grey or white background. Therefore studying other forms of attentional prioritization based on top-down mechanisms such as memory appears more meaningful in real-world scenes.

Studying attentional prioritization in real-world scenes led to the conclusion that fast exogenous and robust oculomotor capture requires a transient motion signal, but without such a signal, new objects are nevertheless prioritized for viewing as slower, less reliable memory processes are engaged to guide gaze – what Brockmole and Henderson (2005a) have named as *memory guided prioritization*. These two different mechanisms of attentional prioritization could potentially be based on separate neuro-anatomic structures, in a similar way to the different structures underlying voluntary (goal-directed) and reflexive (stimulus-driven) saccades (LaBerge, 1995; Maunsell, 1995; Schall, 1995). Both the *subcortical pathway* (superior colliculus) and the *cortical pathway* (frontal eye fields, supplementary eye fields and dorsolateral prefrontal cortex)

involved in the generation of saccades (Pierrot-Deseilligny, Rivaud, Gaymard, Muri & Vermersch, 1995; Schall, 1995) are presumably responsible for the reflexive and goal-directed eye movements respectively, whereas inhibition from the frontal eye fields reaches the superior colliculus through the substantia nigra (Theeuwes, Kramer, Hahn & Irwin, 1998).

On the other side, except for cases of attention capture, there are cases where changes such as object displacements, substitutions or deletions fail to capture the observer's attention, as it has been demonstrated in various change blindness experiments. In these cases the transient signal associated with the changes is being suppressed by various means such as intervening time intervals (Pashler, 1988; Simons, 1996), masks (Rensink, O'Regan & Clark, 1997), occlusions (Simons & Levin, 1998), sudden viewpoint changes (Levin & Simons, 1997) or saccades (Currie, McConkie, Carlson-Radvansky & Irwin, 2000; Grimes, 1996; Matin, 1974; Henderson, 1997; Henderson & Hollingworth, 1999b, 2003; Irwin, 1991). In change detection paradigms it seemed that there cannot be any attentional modulation when the transient signal is suppressed (Franconeri, Hollingworth & Simons, 2005).

This has lead some researchers to believe that attention is driven to low-level scene changes that are associated with the appearance or change of the critical object in oculomotor capture paradigms, such as transient motion signals, changes to surrounding local image features (colour, intensity, contrast, edge density, clutter), disruption of spatial relationships shared among existing objects or occlusion of objects originally present in the scene (Brockmole & Henderson, 2005a). This explanation though cannot

explain why there is attentional prioritization, even though less strong, in the case of memory-guided prioritization (Brockmole & Henderson, 2005a, 2005b, 2008; Matsukura, Brockmole & Henderson, 2009). An alternative explanation of attentional prioritization by onsets might be that the attention system considers the appearance of a new object to be behaviourally relevant, with new objects always prioritized (Yantis, 1993, 1996). This explanation on the other hand cannot account for prioritization by uniquely coloured objects (Folk, Remington & Johnston, 1992; Theeuwes et al 1994) or the disappearance (Chastain et al, 2002) or feature change of objects (Matsukura, Brockmole & Henderson, 2009), so again on its own it is an inadequate explanation.

The role of memory in attentional modulation is also indicated by the fact that reduced viewing time leads to reduced prioritization of objects onset during a saccade (Brockmole & Henderson, 2008). Probably a short exposure to the scene before the onset or change of the critical object hinders the construction of a complete mental representation of the scene that includes the identities and details of viewed objects (Castellano & Henderson, 2005; Henderson & Hollingworth, 2003; Hollingworth & Henderson, 2000, 2002; Hollingworth, Williams & Henderson, 2001; Tatler, Gilchrist & Rusted, 2003; Torralba, Oliva, Castellano & Henderson, 2006). This consequently leads to less efficient comparison of the visual scene with the actively maintained memory representation of the scene and the characteristics of the objects in it which would lead to prioritization in case of discrepancy (Brockmole & Henderson 2005a, 2005b, 2008; Henderson & Castelhamo, 2005; Hollingworth & Henderson, 2002; Hyun, Woodman, Vogel & Luck, 2009; Zelinsky, 2001). This line of evidence from research on attention

capture seems to be leading to conflicting conclusions regarding the amount of information in the visual world around us that is retained in memory within fixations when compared to the conclusions drawn from research on change blindness.

How much of the visual world around us is encoded in memory during viewing and in how much detail has been an area of interest for vision researchers for a long time (Mandler & Parker, 1976; Brockmole, 2009). Experimental data indicate robust memory for the visual form of hundreds of individual objects in scenes (Hollingworth, 2004, 2005b; Hollingworth & Henderson, 2002) and thousands of whole-scene images (Standing, 1973; Standing, Conezio & Haber, 1970) over retention intervals of up to 1 year (Nickerson, 1965, 1968; Shepard, 1967). Many researchers though have interpreted the remarkable extent of change blindness phenomena (for a review see Simons & Ambinder, 2005) as evidence that much less information than what we would intuitively expect is encoded in memory from one glance to the next (Chun & Nakayama, 2000; Irwin, 1992a, 1992b; Irwin & Andrews, 1996; Irwin & Zelinsky, 2002; O'Regan, 1992; O'Regan, Rensink & Clark, 1999; Simons, 1996; Rensink, 2002; Simons & Levin, 1997; Wolfe, 1999). It might be difficult to reconcile these findings, but the role of attention could be the critical mediating factor (Linnell et al, 2005; O'Regan, 1992; O'Regan, Rensink & Clark, 1999; Rensink, 2000a, 2000b; Rensink, O'Regan & Clark, 1997; Simons & Levin, 1997; Tipper, Paul & Hayes, 2006; Wolfe, 1999).

We know that attention is covertly shifted to the area of interest before a voluntary eye movement is executed (Deubel & Schneider, 1996; Henderson, Pollatsek & Rayner, 1989; Hoffman & Subramaniam, 1995; Kowler, Anderson, Doshier & Blaser, 1995;

Sheliga, Riggio & Rizzolatti, 1994; Shephard, Findlay & Hockey, 1986; Rayner, McVonkie & Ehrlich, 1978), with the eyes landing on the position at which the attention is directed (Deubel & Schneider, 1996). Such effects have been extended in cases where the participants prepare lateralized reaching movements as well, biasing visual attention towards the location of the reach (Deubel & Schneider, 1998). Also, when an observer focuses on a spatial location in advance, an onset singleton elsewhere does not capture attention (Theeuwes, 1991; Yantis & Jonides, 1990; Yantis, 1993). Rensink's coherence theory, for example, claims that visual attention is necessary to bind sensory features in a coherent object representation and maintain it in VSTM, whereas unattended sensory representations decay rapidly and are overwritten by new visual encoding (Rensink, 2000a, 2000b).

Visual attention seems to be working as an internal spotlight (Treisman, 1998) or zoom lens (Eriksen & Yeh, 1985) capable of differentiating useful information. In that sense, the main function of attention could be that of consolidating a high-level representation of an object into a stable memory store (Brockmole & Henderson, 2005a) capable of supporting object recognition (Treisman, 1988). For attended objects VSTM and LTM support the accumulation of object representations across shifts of the eyes and attention, and enable construction of relatively elaborate visual representations of scenes (Hollingworth, 2004, 2007). Properties of attention such as the enhancing of spatial resolution (Yeshurun & Carrasco, 1998), acceleration of visual processing (Carrasco & McElree, 2001) and inhibition of the processing of unattended signals (Doshier & Lu, 2000) might be utilized by the visual system for the role of visual

attention as a selection-for-action mechanism (Allport, 1987; Bekkering & Neggers, 2002; Deubel & Schneider, 1996; Schneider 1995). Theories which suggest accumulation of visual information about a scene in memory, while scene viewing progresses (Castelhano & Henderson, 2005; Hollingworth & Henderson, 2000, 2002, 2004; McCarley, Wang, Kramer, Irwin & Peterson, 2003; Peterson, Kramer, Wang, Irwin & McCarley, 2001; Tatler et al, 2003) might be more accurate than memoryless visual exploration theories (Horowitz & Wolfe, 1998).

In general, the role of attention as a selection mechanism has been highlighted in different theories of visual attention (Bundesen, 1990; Duncan, 1996; Humphreys & Müller, 1993; Treisman & Gormican, 1988; Wolfe, 1994). These theories argue that attention can be directed on the basis of many perceptual attributes, describe attention as a competitive process where some candidates are given higher weighting than others, and acknowledge that object selection consequently gives access to all, or at least many, of the object's properties (Humphreys & Riddoch, 2007; Ward, 1999). Even experimental manipulations of object formation revealed that attention is allocated at an object level and not just at a set area in space (Egley, Driver & Rafal, 1994; Linnell, Humphreys, McIntyre, Laitinen & Wing, 2005). The role of attention in action affordance effects on perception will be analyzed more in the last chapter of this thesis.

The paradigm of attentional prioritization was used in the last series of experiments in this thesis to address our interest in exploring action affordance effects at more realistic visual displays and in a free-viewing task where no action was intended. This paradigm provided a rich source of information (including eye-movements) that could be used to

achieve our goal of breaking down the contribution of different factors in the way that action affordances affect visual processing. We were in position to use experimental manipulations that explicitly compare pre-attentive with post-selection effects of action affordance influences on perception. Also use of single objects as critical parts of our stimuli allowed for the study of action affordance effects at their most basic level. Moreover the role of attention modulation in action affordance effects was discussed in the literature review as well as became evident from the results of our experiments. Finally differences between oculomotor capture and memory-guided prioritization were extensively discussed as they are critical for our experimental manipulations and will be further analyzed in conjunction with our main findings in this thesis.

Aim of the Current Thesis

The literature reviewed above provides evidence about the role of action affordances and the potential for interaction in object perception. Results from a number of different experiments were comparatively presented to illuminate different aspects of action affordance effects. In general, action affordance effects were demonstrated to play a role in various aspect of cognition, from perceptual grouping to attentional control and spatial language production and comprehension. This evidence demonstrated that action affordances can provide input at various levels of visual processing and affect cognition in a number of interesting ways. Despite the fact that individual aspects of these action affordance effects have been explored by different studies, there is a variety of issues that remain unresolved. By exploring these issues across all three areas of perception,

language and attentional modulation, this thesis aimed to provide a detailed analysis of the connection between them and the ways that object functionality knowledge can benefit human cognition.

Objects that are both semantically related and their functionality allows for a meaningful combined use were shown to be perceptually grouped (Green & Hummel, 2006; Humphreys & Riddoch, 2001, 2007; Riddoch et al, 2003, 2006; Tucker & Ellis, 1998). Interference of action with perception has also been reported in tasks where the perception of action affordance related features is required or where action affordance related characteristics can be used to benefit task execution (Bekkering & Neggers, 2002; Tucker & Ellis, 2004). There have even been attempts to demonstrate orientation contingent pure physical affordances (Symes, Ellis & Tucker, 2007) or affordances based on the similarity of a stimulus to 3-dimensional objects that afford a specific manipulation (Tipper, Paul & Hayes, 2006).

It has been noted that these action affordance effects are based on a number of processes in different experiments. Action affordances might contribute to perceptual grouping of objects based on both configuration-relevant motoric activations and schema-relevant templates for their interactions. Implied motion has also been recently suggested as a base for such groupings, where simulation of the implied kinematic routines might bind pairs of objects in a single perceptual representation (Riddoch, Bodley-Scott & Humphreys, 2010). Moreover, it has been noted that physical action affordances based on object orientations often have a measurable effect in cases where

an actual action is performed or is intended to be performed and in cases where the task indirectly highlights action relevant features of an object.

Based on evidence about the abstract nature of the encoding of object related information as well as evidence that object orientation, along other important characteristics is part of such object representations, we can safely assume that information about object orientation will be part of the information processed by an observer, even when recognition of the object's orientation is not relevant to the observer's task (cf. Van Eccelpoel, Germeys, De Graef & Verfaillie, 2008). This holds especially true when the orientation is critical for the usual functioning of a specific object, as in the case of the functional end of a non-symmetrical object facing the other object with which it can interact, or when change of its orientation would abolish its normal action affordance related potential. Moreover, given that object information is coded in relation to both other objects as well as the whole scene in which they are situated, we would expect action affordance effects to be evident not only in sparse visual stimuli, but also in complex real world scenes.

At a first stage this thesis aimed to further probe the nature of the perceptual grouping behind the findings of Green and Hummel (2006) which was also hypothesized to explain similar earlier findings in clinical patients (Humphreys & Riddoch, 2001, 2007; Riddoch et al, 2003). Given that small increases in stimuli separation can have a dramatic effect in grouping based on low-level features (Gilchrist, Humphreys & Riddoch, 1996), there might be weakening of object grouping based on their potential functional interaction when the separation between them is increased. Moreover,

functional relations between objects were shown to be sensitive to positioning manipulations in experiments regarding spatial language as well. According to the theories of the nature of the information regarding an object that are encoded in short- and long-term memory though, relational information regarding its relationship with other objects is expected to also be of an abstract nature and this would require the relationship to be unaffected by small metric distance differences between two objects of a functional pair. Moreover, using the same stimulus set for both our variation of the Green and Hummel (2006) paradigm and a linguistic experiment, we aimed to also test how distance manipulations affect action affordances at a different task and at higher levels of analysis, as compared to distance effects on the early perceptual stage of object recognition. It might be the case that distance manipulations have similar effects on both perceptual processing of an object and post-perceptual linguistic descriptions, or alternatively they might appear at a processing level between them.

At a second level, another aim of this thesis was to test action affordance effects in more realistic visual displays and with objects that we encounter in the real world. It might be the case that reports of action effects on perception and object recognition in previous experiments were a result of the abstract nature of the stimuli used or the artificial nature of the tasks employed. Moreover, there are many individual processes that were detected to contribute to the action affordance effects reported in our literature review. Therefore a more flexible paradigm with more data to analyze, in addition to reaction times, would allow for greater separation of the contribution of each of these factors. Perceptual grouping based on potential interactions, schemas, orientation based

physical affordances and directing of attention to action relevant characteristics of an object were all reported to induce measurable action affordance effects on behaviour. Although automatic activation of motor representations is implicitly or explicitly assumed in most action affordance experiments, not all of these effects are purely perceptual in nature.

In extension of our question about the effects of distance at different levels of object perception, by using a novel adaptation of an object prioritization eye-tracking experiment (Brockmole & Henderson, 2005a) we could explicitly compare pre- and post-perceptual effects of action affordances on object perception. The object prioritization paradigm has already been used to explore effects of semantic consistency of an object in a scene (Brockmole & Henderson, 2008); given the similarity between semantic and action consistency manipulations of an object in a scene, we initially needed to verify that our action affordances could be manipulated independently of semantics in our stimulus set. We could then use these action affordance manipulations to compare attentional prioritization and deployment of eye-movements in the case of objects onset at different functional positioning with online action affordance changes of objects that were part of a scene all along. The former would rely on pre-attentive perceptual effects, since the critical object would suddenly and unexpectedly be onset in a scene during viewing, whereas the latter would allow exploration of post-selection effects based on a change of the action affordance of an object that was in view in a scene all along.

CHAPTER 2

EXPLORING THE NATURE
OF PERCEPTUAL
GROUPING OF OBJECTS,
BASED ON ACTION
AFFORDANCES AND THE
FAMILIARITY OF THEIR
INTERACTION.

Probing the Nature of Perceptual Grouping: Distance Effects

As discussed in the first chapter of this thesis, although functional information aids object recognition, it does not necessarily have an effect on object localisation. In the case of the visual neglect patient tested by Humphreys and Riddoch, (2001), functional information facilitated object recognition, but could not be used to speed up the patient's search for the specific object. Therefore it seems that in Humphreys and Riddoch's experiment such relational information was relevant only with respect to the identity of the object and not its exact location. Moreover evidence for the quick decay of iconic representations within a few hundred milliseconds after a stimulus event (Averbach & Coriell, 1961; Di Lollo, 1980; Grimes, 1996; Henderson & Hollingworth, 2003; Irwin, 1991, 1992; Irwin & Yeomans, 1986; Sperling, 1960) was also presented in the previous chapter. Spatial relations specifically were shown to be quantitatively encoded (Irwin, 1991; Phillips, 1974), coding for relations of each object with regard both to other objects and the whole scene (Biederman, 1987; Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996; Mandler & Parker, 1976; Mandler & Ritchey, 1977; Rosielle & Cooper, 2001).

Green and Hummel (2006) hypothesized that objects arranged in a way that facilitates a common action or serves an important function, might be described by explicit perceptual representations employing categorical relations. At a different study though, which employed a distance manipulation of the separation between two objects in a

simple array of geometric shapes (light brightness squares), even a small increase in stimuli separation was sufficient to abolish the advantage of grouping based on low-level features, such as collinear edge- and brightness-based grouping, and subsequently dramatically increase the extent of extinction of the patient (Gilchrist, Humphreys & Riddoch, 1996). This finding regarding low-level based grouping supports theories of early visual processing and selection, which focus on the role of grouping by proximity (Humphreys, 1989; Marr, 1982).

Although such a low-level based grouping was suggested to be different from grouping based on matching a part of a single known object representation or template (Humphreys & Riddoch, 1993), it is possible that high-level grouping might also be sensitive to spatial proximity. A recent experiment by Riddoch and her colleagues concluded that it is implicit motion that simulates the interaction between the two objects and leads to their perceptual grouping in a single concept (Riddoch, Bodley-Scott & Humphreys, 2010). Even in this case we might expect distance manipulations to have an indirect effect in the time-course of perceptual grouping, through its effect on the simulated kinematic routine which allows for the binding of the two objects. Functional relations between objects were shown to be sensitive to positioning manipulations in experiments regarding spatial language as well (Carlson-Radvansky, Covey & Lattanzi, 1999). Again it might be the case that distance manipulations affect functional interactions from as early as their perceptual grouping.

On the other hand, according to the theories about the nature of the object information that is encoded in short- and long-term memory, relational information

regarding its spatial relationship with other objects is expected to also be of an abstract nature. This would require the relationship to be unaffected by relatively small metric distance differences between two objects of a functional pair and, as a consequence, manipulation of the distance between the two objects should not affect the advantage in the detection of a target object forming a familiar interacting pairing with another object. Even in the research mentioned above where distance effects were demonstrated on the perceptual grouping based on low-level visual features, Gilchrist and his colleagues (1996) predicted that in cases where grouping is based on stored templates rather than low-level features it would probably not be so sensitive to inter-item spacing as in their experiment. Perceptual grouping in the Green and Hummel (2006) paradigm is based at higher level interactions, such as knowledge about the functionality of the objects and simulation of the kinematics of the implied interaction. Schema-based knowledge might also be mediating such high-level interactions, as Gilchrist and his colleagues (1996) also predicted. This prediction is in agreement with the evidence of the role of schemas in the action affordance effects presented in Chapter 1. The perceptual grouping supporting the findings in the Green and Hummel paradigm should also be coded at an abstract level, to allow for comparison with schema based stored templates of object interactions.

The combination of the lack of effects of functional information on object localisation as well as the theories regarding the format of spatial relations encoded by the perceptual system allow us to hypothesise that these categorical relations should similarly be independent of absolute spatial positions of the objects in the paradigm used by Green

and Hummel (2006). This hypothesis was tested in our first experiment. Specifically in our first experiment we tested whether the reported perceptual grouping of objects in configurations suitable for a functional interaction would be independent of the distance between the two critical objects.

EXPERIMENT 1.1

Our design replicated Green and Hummel's paradigm (2006), where two objects, separated by a short blank display, were presented in quick succession and, after stimulus presentation, participants were asked to indicate whether a particular pre-determined object was presented to them. The first object was presented at the centre of the screen and faced either to the left or to the right. The second object was presented to the left or right of the first (distractor) object. The participant's task in this paradigm was to recognise if the second (target) object displayed in the series was the target indicated at the beginning of the trial. This paradigm included equal number of positive (target present) and negative (target absent) trials. The semantic relationship between the target object and the label was included as a factor to observe any bias produced by the presence of a distractor that was semantically related to the label [the same factor described the familiarity of the grouping in the case of correct (positive) trials]. The other critical factor manipulated in this paradigm was the orientation of the central distractor object and specifically whether its functional end was facing the target object or away from it, which manipulated the action relation of the two objects and their potential interaction.

A “Distance” variable was added to this paradigm to allow for the manipulation of inter-object separation. In our first experiment, the location of the target object could be at one of two possible distances from the distractor object. Other than this factor, the objects forming the pair could also be either semantically related or unrelated and also positioned either in a functionally interacting or non-interacting configuration. A Signal Detection Theory (SDT) analysis was employed to analyse our data¹. D-primes were used as accuracy measures across conditions and $\log\beta$ was used as a measure of bias; median² reaction times (RTs) of correct responses were also analysed to check for the possibility of speed-accuracy trade-offs.

Based on the results of the Green & Hummel (2006) experiment, the finding of perceptual grouping of objects both semantically related and in the correct positioning to allow for a functional interaction should be replicated by a significant interaction of the Label-Target Relatedness and Functional Relationship factors. The factor of the Distance manipulation might have or not have an effect in this perceptual grouping. According to the evidence of abolishment of functional groupings by stimuli separation in the case of low-level groupings and the detrimental effects of spatial manipulations in language, we might expect that moving the target object further away from the distractor might abolish or at least affect the degree of grouping between the two objects and result

¹ When a cell contained no errors, a corrected formula was used to adjust its values, so that d-primes and $\log\beta$ can be calculated $\{1 - [1/(2n - 1)]\}$ instead of the no-error value of 1} (Green & Hummel, 2006; Wickens, 2002, p. 26).

² Medians were preferred over means in order to avoid the effects of outliers.

in a three way interaction of distance, label-target relatedness and functional relationship. This would indicate that metric information regarding the separation of the to-be-grouped objects is important for perceptual grouping. If on the other hand such perceptual grouping is based on the abstract relation between the two objects, the critical interaction of target-distractor relatedness and functional relationship should not be affected by the distance manipulation.

Method

Participants. Fourteen undergraduate Psychology students of the University of Edinburgh participated in the research for course credit (10 female, 4 male, mean age = 19.14 years). All the participants had normal or corrected to normal vision (7 normal, 7 glasses/contacts) and were naïve to the experimental hypothesis.

Stimuli and Apparatus. Twenty black and white line drawings of common objects subtending approximately 2.3 degrees of visual angle (Figure 3, left) presented on a white background served as stimuli for the current experiment. These were the same stimuli as used by Green and Hummel (2006). Eight of these objects were taken from Snodgrass and Vanderwort (1980) and the rest were created by Green and Hummel for their experiment. These objects could be combined into 10 pairs of semantically and functionally related objects (Figure 3, right). One part of the pair always served as the target object and the other part as the distractor object. The distractor objects were non-symmetrical with only one functional end, so that their proper orientation towards the

target object would establish the functional relatedness whereas improper orientation would abolish action potential.

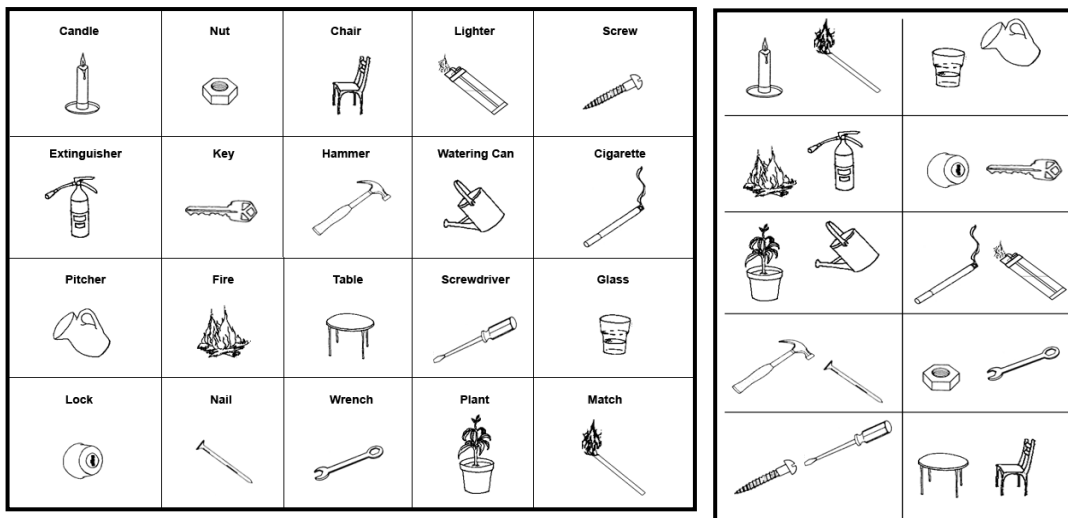


Figure 3: Left: The 20 line drawings of objects used as stimuli and their labels. Right: The 10 pairs in familiar interacting configuration.

Each object was labelled by a word describing it; the labels used to define the targets (Figure 3, left) were displayed on the computer screen in black, 24-point Arial font on a white background.

Stimuli were presented on a 14" Dell monitor (1280 x 1024 resolution). Participants were seated at a distance of approximately 66 cm from the computer monitor. The experiment was run on E-Prime v.2, which presented stimuli in an 800 x 600 bmp image and collected participants' responses.




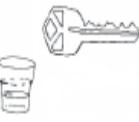


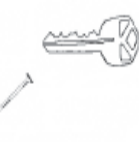

Design and Procedure. Four within-subjects factors were orthogonally crossed (Figure 4). Label-Distractor Relatedness (related or unrelated) coded the semantic relation between the label and the distractor object³, Functional Relationship (interacting or not interacting) coded the functional interaction between the distractor and target object and Distance (close or far) coded the distance between the two objects. There was equal number of positive trials, where the target matched the label, and negative trials, where the target did not match the label (Trial Type: positive or negative).

Participants took part in a computer-based object identification task. Each participant completed 320 trials and the duration of the experiment was 20-30 minutes. Each trial started with the presentation of the label of the target-object at the centre of the display until the participant pressed the SPACEBAR on the keyboard to start the presentation of the stimuli. Then a fixation cross replaced the label for 750 msec. After that the two objects appeared in quick succession, separated by a blank screen (ISI: Inter-Stimulus Interval = 30 msec, SOA: Stimulus Onset Asynchrony = 60 ms). The first object was the distractor which always appeared at the centre of fixation for 30 msec and then disappeared. After the blank screen with only the white background, the target object appeared for 30 msec either to the left or right of the distractor (centre of fixation).

³ It has already been mentioned that in the Green and Hummel (2006) paper the relatedness factor referred to the semantic relationship between the target object and the label (instead of the distractor object) to test for any possible bias produced by the presence of a distractor that was semantically related to the label. Moreover defining relatedness in terms of the relationship of the target object to the label allowed for both positive and negative trials at each level of the relatedness factor, which are necessary for the Signal Detection Theory analysis. The label-target relatedness described the familiarity of the grouping in the case of correct (positive) trials and it also allowed for an orthogonal design to be analyzed by SDT, as illustrated in Figure 4.

Finally another blank display remained on screen until the participant's response of whether the target object that appeared was the one labelled at the beginning of the trial. If the labelled object was presented the participant should respond by pressing the Z key, or press the M key if the target object was not the one labelled at the beginning of the trial. There was no time-out for the response button press. Participants were instructed to respond as quickly but also as accurately as possible.

The participants did not know whether the target object would appear to the left or to the right of fixation and both locations were used equally often. The distance of the target object from fixation (the centre of the display) would also vary according to the experimental manipulation. It could be either 100 pixels (4° visual angle) from fixation for position 1 (close) or 200 pixels (8° visual angle) from fixation for position 2 (far). Each distance occurred equally often.

		Related		Unrelated	
		Interacting	Not Interacting	Interacting	Not Interacting
Positive					
					

The label is "glass" in these examples.

Figure 4: The 8 experimental within-subjects conditions and an example for each condition (figure taken from Green & Hummel, 2006). In Experiment 1.1 a further variable manipulating the distance between the two objects was added to this design.

Results

Crossing of our variables of *Label-Distractor Relatedness* and *Functional Relationship*, as in the Green and Hummel (2006) experiment, with further manipulation of the *Distance* variable led to 8 within-subjects conditions. Signal Detection analysis was employed for each participant's data to measure his or her perceptual sensitivity and response bias. Response times (RTs) in each condition were also computed. These measures were subsequently analyzed in separate 3-way analyses of variance (ANOVAs) to determine which factors affected performance. Results of the analyses for perceptual sensitivity, bias and RTs will be presented separately.

In this and all experiments described later in this thesis, an alpha level of .05 was adopted as criterion for statistical significance and where assumptions of sphericity were violated, Greenhouse-Geisser corrections to the appropriate degrees of freedom were used.

Perceptual Sensitivity. Mean d' scores for each of the 8 within-subjects conditions were calculated (Figure 5). A repeated measures $2 \times 2 \times 2$ (*Label-Distractor Relatedness* \times *Functional Relationship* \times *Distance*) ANOVA on the mean accuracies at each condition revealed no significant main effects (all p 's $> .26$), but there was a significant interaction between Label-Distractor Relatedness and Functional Relationship [$F(1, 13) = 6.222, p = .027$].

Planned comparisons (Figure 5) revealed a significant effect of *Functional Relationship* for the *Related* ($t = 2.251, df = 13, p = .042$) but not the *Unrelated*

condition ($t = -1.049$, $df = 13$, $p = .313$), with the accuracy for *Related Interacting* objects ($d = 3.43$) being higher than for *Related Not Interacting* objects ($d = 3.23$).

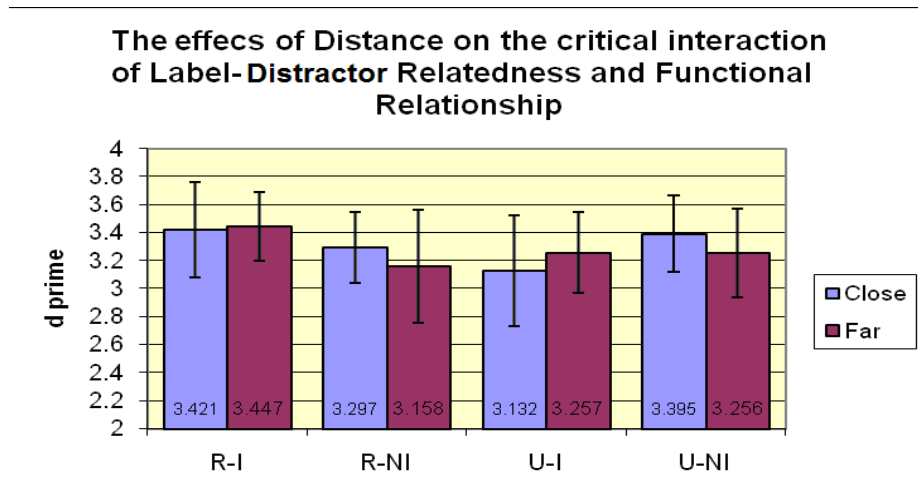


Figure 5: Mean d' scores for each within-subjects condition. Error bars represent 95% confidence intervals.

Response Criterion. Mean criterion measures ($\log\beta$) for each of the 8 within-subjects conditions were calculated (Figure 6). Although the criterion in the case of Related-Interacting stimuli was slightly less strict than in the other conditions, a repeated measures $2 \times 2 \times 2$ (*Label-Distractor Relatedness* \times *Functional Relationship* \times *Distance*) ANOVA revealed no significant main effects (all p 's $> .18$) nor interactions (all p 's $> .23$).

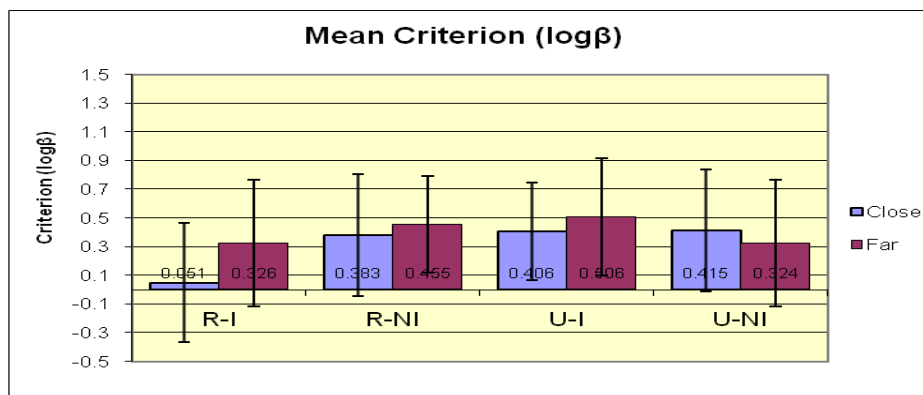


Figure 6: No significant differences in the criterion used in each condition. Error bars represent 95% confidence intervals.

RTs. The Reaction Times of correct trials for each experimental condition were analyzed to check for potential speed accuracy trade-offs among these conditions (Figure 7). The median RTs for each condition were analyzed with a 2 x 2 x 2 repeated measures (*Label-Distractor Relatedness* × *Functional Relationship* × *Distance*) ANOVA. Analysis revealed no significant main effects of any variable (all p 's > .20) and no significant interactions (all p 's > .14).

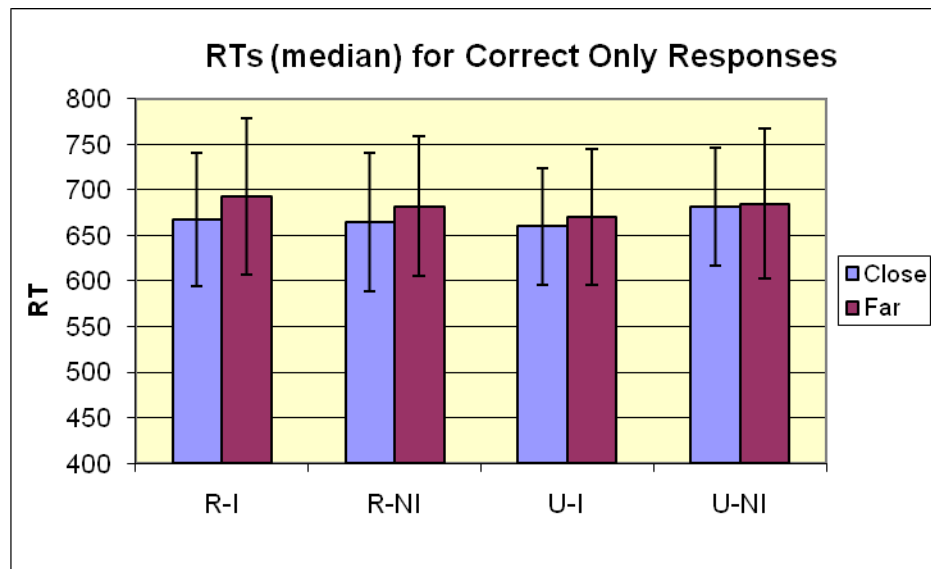


Figure 7: Median RTs of correct responses at each experimental condition for close and far targets. Error bars represent 95% confidence intervals.

DISCUSSION

Our results of the signal detection analysis replicated the original findings of Green and Hummel (2006) who reported an interaction between Label-Distractor Relatedness and Functional Relationship. Our new variable of interest, Distance, had no effect on our results, neither as a main effect nor as a part of any interaction. The Label-Distractor Relatedness variable in simple words captures the semantic relationship of the pairing of

the objects used as stimuli, so the critical interaction shows that the functional relationship between the objects affects perception only in the case of perceptual grouping of semantically related objects. Green and Hummel use the term “familiar interacting objects” to refer to this critical interaction of both semantic relationship and appropriate positioning allowing for a functional interaction. Also in accordance with the original experiment no significant difference in the criterion used at any of the within-subjects conditions was found. The new variable of interest, “Distance”, again did not have any effect in the strictness of the criterion used by participants. Finally, participants’ RTs were not affected by any of our variables. Although giving an answer when the target object was further away from the distractor required some additional time, this difference did not reach significance. The lack of RT effects validate that our findings are not caused by a speed-accuracy trade off.

Overall, there was an advantage in the perception of familiar groupings of functionally related objects, compared to the case of the same objects in a non-interacting configuration. Contrary to Green and Hummel’s results though, no adverse effect was found when the distractor object was not related to the target object; performance of our participants in semantically unrelated object pairings was similar, whether they were positioned towards a potentially functional interaction or not. As mentioned in the introduction, this effect has been suggested to be based on the perceptual grouping of the familiar functionally related objects (Green & Hummel, 2006). Although the facilitatory effect of the functional relationship is based on the familiarity of the grouping of the two objects, our current results suggest that this

perceptual grouping is resistant to spatial changes of the distance between the two objects, at least through the range tested here.

Of course it could be the case that our manipulation was not strong enough and the distance between the two objects was not large enough to abolish their perceptual grouping. Another possible explanation could be that the sparse and abstract nature of the stimuli we used (line drawings on a white background) might allow for grouping of the objects independently of their distance; the lack of a background or other objects to be used as a reference point, as well as the fact that the size of the objects used as stimuli was not scaled, to keep a similar size of all stimuli used in the trials, might have made this paradigm less susceptible to absolute distance manipulations and more inviting of abstraction.

Our result is anyway in agreement with the prediction that grouping based on stored templates rather than low-level features should not be so sensitive to inter-item spacing manipulations (Gilchrist et al, 1996). Our stimulus set was adequately sufficient for setting up a linguistic experiment to test the effects of the same distance manipulation on acceptability ratings of sentences describing the spatial relationship between the two objects and compare them to the paradigm of perceptual effects on target recognition. Experiment 1.2 was designed to deal with the issue of the effectiveness of our manipulation, by looking to see if the exact same spatial manipulation will affect performance on other tasks like spatial language usage. Finally the issue of the nature of our stimulus set was addressed by a different experimental setup and more realistic

stimuli in our last series of experiments, where participants' eye-movements were tracked during viewing of real world scenes.

EXPERIMENT 1.2

Given the evidence about effects of functional relationships on spatial language, a further exploration of the nature of the facilitation achieved by perceptual grouping of familiar interacting objects was probed in our second experiment. Our combination of the literature on linguistic effects of object functionality with research related to perceptual grouping based on functional interactions, aimed at exploring the relationship between perceptual and linguistic effects of the functional relationship between pairs of objects. Based on the evidence regarding object functionality effects on spatial language, as described in Chapter 1, and given that distance is encoded during the processing of projective spatial terms, such as “*above*”, “*left*” or “*front*” (Carlson & van Deman, 2004), we would expect the goodness of an object-centred description at our linguistic rating task to be affected by the distance between the two objects in the functional interaction paradigm.

Our aim in Experiment 1.2 was to test how the exact same distance manipulations affect action affordances on a different task and at later levels of visual processing, and compare the results with our findings regarding the lack of distance effects on the early perceptual stage of object recognition. In Chapter 1 it was hypothesized that such a comparison might reveal that distance manipulations have similar effects on both perceptual processing of an object and post-perceptual linguistic descriptions, or that

such distance effects appear at a processing level between perceiving an object in relation to another object and describing their relationship. Given that our first experiment indicated there was no effect of our distance manipulation in the perceptual grouping of semantically related objects configured in a potentially interacting positioning, testing our stimuli and the same distance manipulation in a spatial description rating paradigm could shed further light in this result.

One limitation we previously pointed out regarding the Green and Hummel (2006) paradigm and Experiment 1.1 was the abstract nature of the visual display used. Stimuli were line drawings of objects situated on a white background, and many of these objects were not equally scaled to avoid confounding of our results by low level features such as differences in size between objects. It was hypothesized that maybe such stimuli were calling for a certain level of abstraction which bypassed our distance manipulations of objects separation. By testing the same stimulus set in an experiment rating the spatial linguistic description of the interaction between the two objects, where the distance manipulation is expected to have an effect based on the related literature, we could test if our manipulation was strong enough to affect later object processing levels and whether the lack of its effect on the perceptual experiment was due to the relationship between object representations being abstracted from our stimuli.

In Experiment 1.2 we explored functionality effects on spatial language using a similar experimental design as in our variation of the Green and Hummel (2006) paradigm. The same distance manipulations and the exact same stimuli that were used in Experiment 1.1 were utilized. For this experiment, we presented both objects from each

pair in Experiment 1.1 on a white background and included a spatial description of their relationship on the same image. Participants were asked to rate the description in a 1-7 Likert scale according to how well they thought the sentence was describing the spatial relationship of the objects. Spatial terms that were previously found to be preferably used with object-centred reference frames (which made them more sensitive to show object functionality manipulations) were utilised for the spatial descriptions (in front of – behind). There were both correct and incorrect trials (e.g. the functional end of a jug would be facing away from a glass while the sentence “The glass is in front of the jug” would be accompanying the image). The same variables as in the first experiment were used to describe the semantic and functional relationship between the two objects (Target-Distractor Relatedness, Functional Relationship, Distance), with the only exception of using 5 different object separations in the distance manipulation, so three more distances (manipulating separation of the target object from the distractor) were added to the two distances used in our first experiment.

By comparing the results of Experiments 1.1 and 1.2, we were interested in whether the distance separation would affect the perceptual advantage of the interaction in the same way that the goodness of description is affected, or even if increased object separation would cancel the perceptual advantage of functional grouping of semantically related objects. By comparing the ratings for the spatial descriptions in the same positions used in our first experiment we can infer whether perceptual and linguistic changes due to spatial configuration occur at the same point of objects’ absolute spatial separation or whether perceptual grouping is based on more abstract relationships and is

unaffected by small absolute distance manipulations. Given the lack of an effect of distance on Experiment 1.1, if the same distance manipulation was found to have an effect on this linguistic experiment, it would demonstrate that those distance effects occur between perception and language.

It was not clear whether the semantic relationship between the objects would interact with functional relationship in this paradigm where no limitations on the perception of the objects were imposed, but the effects of distance were more of a critical factor. A main effect of distance or interaction with any of the other factors would imply that the same distance manipulation that did not have an effect in the perception of an object and its grouping with a familiar interacting distractor does affect the spatial description of the two objects post-perceptually and that these effects take place between perception and language. If, on the other hand, no effect of distance was demonstrated in our experiment, it would imply that our finding that perceptual grouping is not affected by distance manipulations in the first experiment was based on the abstract and artificial nature of our stimuli and design. Answering these questions is critical in extending the finding of perceptual grouping and action affordance effects on perception on more realistic stimuli, such as real-world scenes.

Method

Participants. Fourteen volunteers (recruited from Edinburgh University's career services website), participated in the research for an honorarium of £5 (9 female, 5 male,

mean age = 19.93 years). All the participants had normal or corrected to normal vision (6 normal, 8 glasses/contacts) and were naïve to the experimental hypothesis.

Stimuli and Apparatus. The stimuli and apparatus used were identical to those in Experiment 1.1 except for the following changes. First, the located object was positioned in one of five possible distances from the reference object⁴. Second, a sentence describing the spatial relationship of the two objects was added on the visual display of the stimuli. This sentence was displayed on the computer screen in black, 24-point Arial font at the bottom of the image with the pair of objects above it.

Design and Procedure. Five within-subjects factors were orthogonally crossed (Figure 8). Target – Distractor Relatedness⁵ (Related or Unrelated) coded for the semantic relation between the located and the reference object and Functional Relationship (Interacting or Not Interacting) again coded for their functional interaction. On interacting trials, the reference object was oriented towards the located object so as to establish a functional interaction whereas on non-interacting trials the reference object was oriented away from the located object (the reference object is non-symmetrical, therefore there is only one functional end) disrupting the functional interaction. Also Distance (1-5) coded the distance between the two objects, but in this experiment there

⁴ The terms used here to describe the two objects follow the terminology in the spatial language literature. Nevertheless the terms of the “located object” and “reference object” coincide with the “target object” and “distractor object” in Experiment 1.1 respectively.

⁵ Note that Target – Distractor Relatedness here refers to the relationship between the two objects, unlike the first experiment.

were 5 possible positions with the located object positioned 50 pixels (2° visual angle) further away from the reference object for each position (1=100 pixels, 2=150 pixels, 3=200 pixels, 4=250 pixels, 5=300 pixels). Trials were included where the spatial configuration of the two objects matched the description (sentence) and also trials where the two did not match (Trial Type: positive or negative) and also the located object could appear either to the left or right of the reference object (Target Position: left or right).

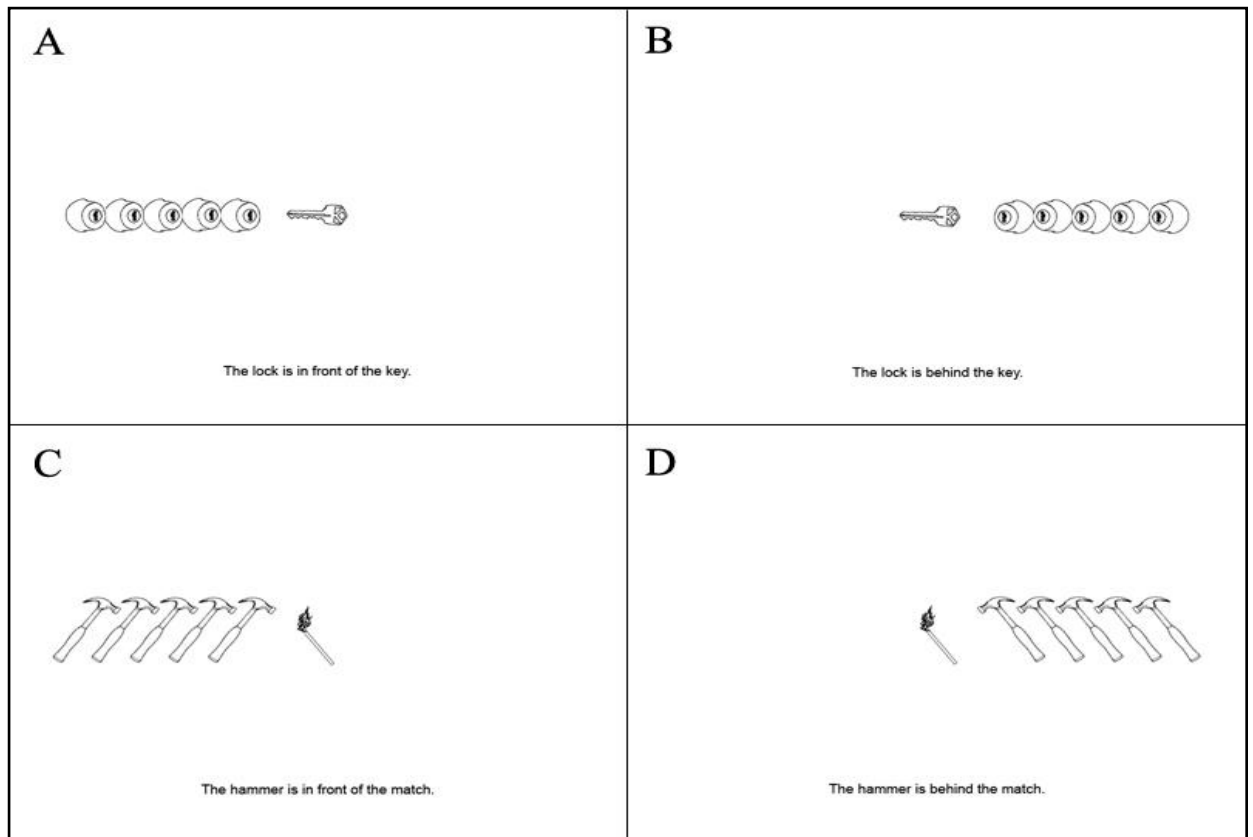


Figure 8: An example of the five possible positions of the located object, due to the distance manipulation in Experiment 1.2. Only one of these positions was displayed with the central reference object at each trial. The images in the top row (panels A and B) present an example of semantically related objects, whereas the images in the bottom row (panels C and D) present an example of semantically unrelated objects. The left column shows examples of an interacting functional relationship (panels A and C) and the right column shows examples of a non-interacting functional relationship (panels B and D). In the examples above correct trials are presented. Incorrect trials were created by swapping the sentences, for example using the image on panel A or C with the description from panel B or D respectively.

The participants took part in a computer - based task, rating the appropriateness of image - sentence matching. In order to build the verbal description for the spatial relationship between the two objects (sentence), two different kinds of terms were used (behind/in front of) to create an object-oriented reference point, which has been reported to be sensitive to manipulations of the functional relationship between objects (Miller & Johnson-Laird, 1976; Ullmer-Ehrich, 1982; Carlson-Radvansky, 1996, 2000). In other words the participant's task was to rate on a 1-7 Likert scale how well each sentence describes the relationship between the objects. Participants were encouraged to use the whole scale. Each participant completed 800 trials and the duration of the experiment was 30-40 minutes.

At each trial the pair of objects was presented with the reference object always being at the centre of the display and the located object at one of five possible locations either to the left or right of the reference object. A sentence describing the spatial relationship of the two objects was accompanying the pair at the bottom of the image. This sentence could be for example "The lock is in front of the key" or "The lock is behind the key". The image remained on the screen until the participant responded. The located object appeared to the left or to the right of fixation equally often. On half the trials the location of the located object matched the description (positive); on the other half the location did not match the description (negative). The distance of the located object from fixation (the centre of the display) would vary according to the experimental manipulation. It could be located from 100 pixels (4° visual angle) to 300 pixels (12° visual angle) from

fixation, moving the located object 50 pixels (2° visual angle) further away from the centre for each of the five possible positions.

RESULTS

A $5 \times 2 \times 2$ (Distance \times Target – Distractor Relatedness \times Functional Relationship) repeated measures ANOVA was employed on the ratings for positive trials only, where the description (sentence) was correct according to the target object's position in relation to the distractor. This analysis revealed a significant main effect of Distance [$F(4, 52) = 5.832, p = .001$] with the ratings following an approximately linear drop as the distance between the target and distractor was increased (see Figure 9). There was also a significant main effect of Target – Distractor Relatedness [$F(1, 13) = 8.646, p = .011$], with related objects ($M_R = 5.091$) getting higher ratings than unrelated objects ($M_U = 4.903$), and Functional Relationship [$F(1, 13) = 7.111, p = .019$], with objects in interacting configuration ($M_I = 5.187$) getting higher ratings than not interacting ones ($M_{NI} = 4.807$).

Most importantly, there was also an interaction between Distance and Functional Relationship [$F(4, 52) = 3.204, p = .02$]. Although a simple effects analysis revealed a significant effect of distance on both levels of Functional Relationship [Interacting: $F(1, 13) = 258.23, p < .001$; Not Interacting: $F(1, 13) = 555.79, p < .001$] further analysis

showed that distance affected the ratings mainly in the case of interacting configuration⁶. Even by a simple inspection of the data, the effect of distance on the case of not interacting objects seems minimal, if any (Figure 10). A trend analysis was used to explore this interaction.

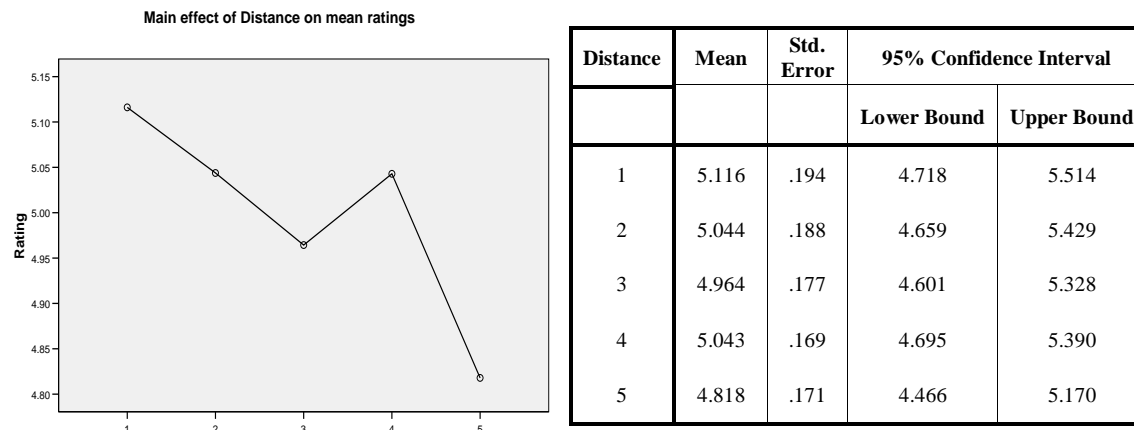


Figure 9: Analysis reveals a gradual drop of the ratings as the target is moved further away from the distractor.

As we can see in Figure 10 though, ratings in Distance 4 seem to be higher than expected, with respect to the effect of increasing the distance between target and distractor on participants' ratings, in both interacting and non-interacting conditions, so this significant effect might be an artefact of the increased ratings in position 4 in

⁶ In the case of interacting objects there was a significant decrease in ratings between distance 1 and 3 ($I_1 = 5.377$, $I_2 = 5.275$; $t = 2.796$, $df = 13$, $p = .015$), 1 and 5 ($I_1 = 5.377$, $I_5 = 4.907$; $t = 4.999$, $df = 13$, $p < .001$), 2 and 5 ($I_2 = 5.275$, $I_5 = 4.907$; $t = 4.949$, $df = 13$, $p < .001$), 3 and 5 ($I_3 = 5.180$, $I_5 = 4.907$; $t = 3.821$, $df = 13$, $p = .002$) and 4 and 5 ($I_4 = 5.195$, $I_5 = 4.907$; $t = 4.198$, $df = 13$, $p = .001$). Least significance difference post hoc tests reveal only one pair ($NI_4 = 4.891$, $NI_5 = 4.729$; $t = 2.384$, $df = 13$, $p = .033$) in the not interacting condition where distance seems to affect the participants' ratings.

general. This can be graphically represented if we estimate a line of best fit in the scatter plot of the mean ratings for each of the five distances in the interacting and not interacting conditions separately. The slope of the regression line in the not interacting condition ($r = .16$) is much lower than the one in the Interacting condition ($r = .85$) and quite close to zero (Figure 10).

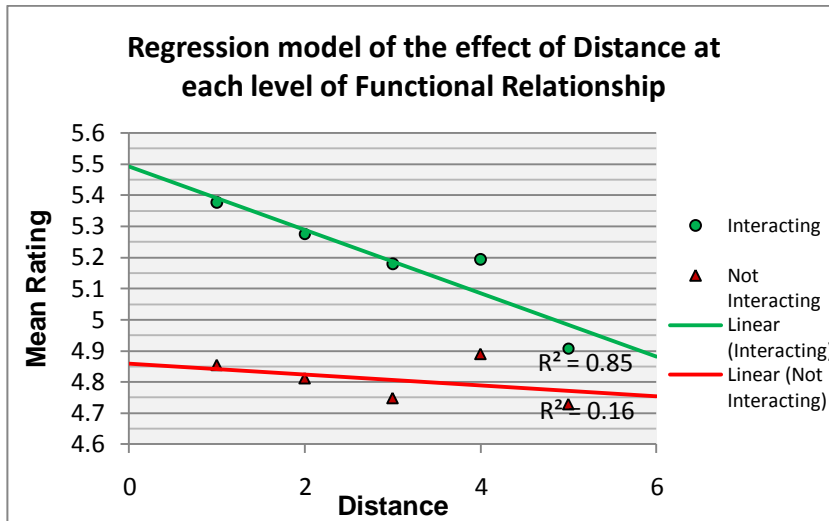


Figure 10: Mean ratings of the appropriateness of the terms “in front of”/”behind” as a function of distance for interacting (green circles) and not interacting (red triangles) conditions.

Positions 1 vs. 3. Data were re-analyzed with a similar 3-way ANOVA on the ratings for positions 1 and 3 only, which were of specific importance for the distance manipulation in our previous experiment, to check if these two positions differed significantly and verify the results of the previous post hoc analysis. This analysis revealed a main effect of Distance [$F(1, 13) = 8.356, p = .013$], Target – Distractor Relatedness [$F(1, 13) = 5.031, p = .043$] and Functional Relationship [$F(1, 13) = 12.917, p = .003$]. Mean ratings were higher in the case of distance 1 ($M_1 = 5.116$) when compared to distance 3 ($M_3 = 4.964$), related objects ($M_R = 5.148$) got higher ratings

than unrelated objects ($M_U = 4.932$) and interacting objects ($M_I = 5.279$) received higher ratings than not interacting objects ($M_{NI} = 5.279$).

Restricting the analysis in the positions of interest 1 and 3 gave us identical results with the previous analysis, with the only difference of a lack of a significant interaction between Distance and Functional Relationship, but in this case we had restricted our analysis in only two data points of the distance manipulation and so this analysis was probably too focused to detect such an interaction (and underpowered because it used a small sample of our data).

DISCUSSION

Overall analysis of the ratings of spatial descriptions of the relationship between two objects, such as “in front of” or “behind”, revealed sensitivity in the distance manipulation, with greater separation between them leading to reduced ratings. The cost of the distance manipulation was equal though for both semantically related and unrelated pairs of objects, although groupings of semantically related objects received in general higher ratings than unrelated ones. Nevertheless distance interacted with the functional relationship between the two objects; the distance manipulation did have a stronger effect when pairs of objects, independently of their semantic relationship, were positioned towards a potential functional interaction with the functional end of the distractor object oriented towards the target object. Objects positioned in interacting configurations were also rated higher than non-interacting configurations.

The results of Experiment 1.2 demonstrated that the lack of a distance effect in the perceptual grouping of the objects in the stimulus set we used in Experiment 1.1 was not due to their abstract nature and that our manipulation was strong enough to have a measurable effect in a different task regarding later levels of object processing. When participants were asked to rate the linguistic description of the interaction between the two objects, the same distance manipulation had a significant effect on the ratings of the appropriateness of those spatial descriptions. The results of our second experiment will be discussed more analytically in the general discussion, in comparison with the results of the first experiment.

GENERAL DISCUSSION – Experiments 1.1 and 1.2

As a general conclusion, the combination of the results of Experiments 1.1 and 1.2 reveal that even though objects seem to remain perceptually grouped independently of spatial distance manipulations, there is a negative effect of increasing the distance between the two objects in people's linguistic description of their spatial relationship. Such distance effects appear at a processing level between object perception and post-perceptual description of its relationship with another object. The effect of distance in the post perceptual spatial description is more detrimental in the case of functionally interacting configuration of the objects compared to configurations not allowing the possibility of a functional interaction, but this effect is independent from the familiarity of the grouping (no interaction of the Functional Positioning factor with Target-Distractor Relatedness). Although similar effects were stronger in the case of

semantically related objects, in experiments where participants were asked to physically place located objects above other reference objects, participants were also biased to place unrelated objects towards the functional part of the reference object (Carlson-Radvansky et al, 1999). This is compatible with our specific finding that effects of the functional configuration were observed in both semantically related and unrelated pairs of objects.

Our results add to the evidence suggesting that objects are not just static, physical entities, but they are rather dynamic representations that can change according to various factors. These factors include the learning of statistical relations between stimuli, determined particularly by whether objects are or can be used together, as well as by intentions for action (Humphreys & Riddoch, 2007). The way that these action affordances can affect object representations though is not equally automatic or abstract across different stages of analysis of a visual display.

At early perceptual stages, pairs of object both semantically related and functionally interacting can be grouped together to facilitate recognition and encoding of the objects in the visual display in VWM and in LTM subsequently. Perceptual grouping in our paradigm is probably based at higher level interactions, such as knowledge about the functionality of the objects, relevant schemata and simulation of the kinematics of the implied interaction. This perceptual grouping operates at a level of abstraction that allows for comparison with schema based stored templates of object interactions and also allows for this facilitating effect independently of the distance separation of the two objects. In the case of the neglect patient tested from Humphreys and Riddoch (2001) for

example, it was shown that the relation of the two objects facilitated their recognition but their characteristics were not detailed enough to facilitate localisation. Based on the evidence of the relational coding of information in a visual display (Biederman, 1987; Hummel & Biederman, 1992; Hollingworth, 2006; Hummel & Stankiewicz, 1996; Mandler & Parker, 1976; Mandler & Ritchey, 1977; Rosielle & Cooper, 2001), such a level of abstraction would be necessary to allow for such a use of functional interactions by the visual system in more realistic situations encountered by an observer in everyday life. The visual input that our brain has to process is usually much more rich and cluttered than the displays used in experimental situations such as our initial experiments.

At later levels of post-perceptual processing though, such as describing the spatial relationship between two objects after they have been identified, details in the visual display become more important and there is a need for more than an abstraction of the relationship between them. The distance between the two objects has notable effects in the selection of the terminology used to describe their relationship as well as in the understanding of such spatial descriptions usage, in accordance with previous research (Carlson-Radvansky, Covey & Lattanzi, 1999; Carlson-Radvansky & Radvansky, 1996; Carlson-Radvansky & Tang, 2000).

In linguistic experiments which study functional biases it has been reported that dynamic - kinematic routines corresponding to forces or principles that govern the objects' interaction, in addition to geometry and object knowledge, may be contributing to the interpretation of projective terms (such as *above* and *right*), but not proximity

terms such as *near* (Coventry & Garrod, 2004). Spatial language is interpreted by constructing a simulation of the interaction between the objects, drawing not only on general knowledge of their association but also on underlying forces and principles that govern their actual interaction. During the online interpretation of a spatial description, a weighted combination of various types of information (geometric, dynamic-kinematic, and object knowledge) is formed (Coventry & Garrod, 2004; Carlson-Radvansky, Covey & Lattanzi, 1999).

Similarly, in object perception and neglect research, it has been demonstrated in a recent experiment that motion is implicitly coded and helps to link objects together as a perceptual unit, which can consequently reduce the spatial bias in selection that produces extinction (Riddoch, Bodley-Scott & Humphreys, 2010). In general, such simulations of the interaction between objects integrate general knowledge of the association among the objects, dynamic-kinematic information that may define the interaction and constraints imposed by the spatial term. These simulations include modeling all this information as a set of perceptual and action representations (Barsalou, 1999; Coventry & Garrod, 2004; Glenberg & Kaschak, 2002; Glenberg & Robertson, 2000; Zwaan, 2004).

In agreement with theories that link language comprehension to action and perceptual processes, Carlson and Kenny (2006) conclude that the reported functional bias in familiar interacting pairs of objects is based on the simulation of an interaction between the objects rather than on mere activation of general knowledge related to the association between a located object and a functional part. This could be explained by a theory such

as an “active zone” where located objects are biased towards different functional parts and the identity of the located object is defining which parts will become functionally prominent on the basis of their association. In spatial language experiments simulated interaction among objects may be differentially enabled by the spatial term used to describe the relation, an idea consistent with the reported differences between various spatial terms (e.g. in the reference frame selection, Carlson-Radvansky & Irwin, 1994; Carlson-Radvansky & Radvansky, 1996; Carlson-Radvansky & Tang, 2000). In this sense language works as a cue for the comprehender to construct an experiential simulation that includes both perceptual and action components, and with the details of the situation actively constraining interpretation (Chambers, Tanenhaus, Eberhard, Filip & Carlson, 2002).

Our findings of the abstract nature of the perceptual grouping of semantically related objects when they are positioned in an appropriate way to allow for their functional interaction reveal that this phenomenon might have measurable effects in the real world and allows for extension of their research in real-world situations, despite the complexity and the abundance of information to be processed. This result justifies our later experiments which try to extend the findings of action affordance influences on perception in a free-viewing task of real world scenes. Moreover the evidence reviewed in the paragraphs above suggests that simulation of the interaction among two objects is partly at least behind their perceptual grouping. In view of a semantically familiar pair of objects that can potentially interact, the observer pre-attentively simulates this interaction from the early stages of visual recognition process and the activation of

motor related characteristics of the interaction helps bind the two objects in a single percept. Interestingly a similar simulation of the interaction of the two objects has been suggested to play a role to the interpretation as well as the use of spatial terms during the online interpretation of spatial relations.

In the literature related to the perception of action affordances, it is worth noting a finding in a paradigm recently used by Tucker and Ellis (2004) that affordance compatibility effects are activated independently of the visibility of the object, as well as by both object images and object names (words). This finding indicates that the activation of a compatible motor response does not necessarily rely on the transient on-line processing associated with the so called “action stream” in the dorsal pathway, but is rather induced by longer-term object–action associations. Coding of the action relationship, which can consequently modulate visual selection, seems to be done implicitly (Riddoch, Humphreys, Edwards, Baker & Wilson, 2003). The intention to perform an action taps into the same mechanism with the performance of an actual action, resulting in a top-down modulation of visual processes that favour object features that are directly related to the ongoing specification of parameters for action control, such as orientation characteristics setting the parameters of a grasping movement (Prinz, 1997).

Therefore we can imagine that irrespective of their nature, action affordance activations might be having similar effects with an area which has been well researched in the recent years, that of semantic effects on perception. In a sense action affordance effects could also behave in a semantic-like manner. Moreover, it has been demonstrated

that stimuli appearing at locations at the end point of a movement enjoy enhanced perception, relative to stimuli falling at nearby locations (Deubel, Schneider & Paprotta, 1998), which has been attributed to the anchoring of attention to the movement. This finding highlights the role of attention manipulation by action affordances. These hypotheses of the semantic like effects of action affordances and the mediating role of attention will be further explored in the last section of my thesis by a series of eye tracking experiments.

In the next chapters we aim to analyze action affordances at a more basic level of single objects and again separately explore these effects at different levels of processing, from pre-attentive to post-selection effects. Discussion of experiments exploring perceptual grouping of functional interactions of pairs of objects, as well as Experiments 1.1 and 1.2 presented so far contributed in our conclusion that the reported action affordance effects are partially driven by a number of factors, such as perceptual grouping, attention modulation and physical object affordances. To explore the contribution of each of these factors we manipulate object functionality outside object interactions. We rather used manipulations of object positioning in real-world scenes and violations of object functionality schemata. Moreover, we focused more on the role of attention and tried to further explore influences of action affordances and object functionality on attention modulation.

CHAPTER 3

EXPLORING PRE- ATTENTIVE AND POST- SELECTION EFFECTS OF ACTION AFFORDANCES IN AN OBJECT PRIORITISATION PARADIGM USING REAL WORLD SCENES.

PART I:

EVIDENCE FROM EYE-TRACKING

Object Prioritization: Evidence from Eye Movement Research

In Chapter 1 discussion of evidence from eye-movement based research considered the factors that affect deployment of eye-movements as well as the two mechanisms that were found to support the attentional prioritization of objects. Neuro-anatomic structures that could potentially support oculomotor attention capture and memory guided prioritization were also reviewed. Moreover, the contribution of stored templates or schemas in the deployment of eye-movements was discussed. A series of experiments concerning change blindness were briefly discussed concerning the seemingly opposite indication they provide regarding encoding of a scene within saccades, as opposed to the concrete performance of spotting changes in the object prioritization paradigm. This comparison, in addition to theory about the role of schemas led to a discussion about the role of attention and the need for active encoding of scene content as opposed to automatic imprinting of iconic representations.

Recent experiments from Matsukura, Brockmole and Henderson (2009) have probed more on the issue of whether changes to surface features of existing objects that are visible throughout the viewing period can trigger attentional prioritization. They used a paradigm similar to the original devised by Brockmole & Henderson (2005) in order to explore the potential prioritization of colour changes via oculomotor capture and smemory-guided prioritization. They found that colour changes are prioritized in a

qualitatively similar way to onsets, although quantitatively attention capture in the case of colour changes was less efficient. As for the role of transient motion signals, changes that occurred during a fixation were prioritized faster and more frequently than those that occurred during a saccade, as in the onsets paradigm (Brockmole & Henderson, 2005a). In addition, memory-guided prioritization was similar as in the case of object onsets, indicating that object feature information such as colour are also part of the on-line representations generated during scene viewing, adding to similar evidence that object identity, position and orientation are characteristics of objects that are maintained in memory (Aivar, Hayhoe, Chizk & Mruczek, 2005; Henderson & Hollingworth, 1998a, 2003; Hollingworth, 2004, 2006, 2007; Hollingworth & Henderson, 2000, 2002; Smilek, Eastwood & Merikle, 2000; Tatler, Girlchrist & Rusted, 2003).

On the other hand, Brockmole & Henderson (2008) have extended their paradigm to test whether the semantic consistency of the critical object to be onset or offset in the scene could affect the efficiency or speed of attentional prioritization. Although there is no agreement in whether semantically inconsistent objects attract attention in a pop out manner at a stage of initial selection (Loftus & Mackworth, 1978) or over time (de Graef et al, 1990; Friedman & Liebelt, 1981; Henderson et al, 1999), we know that viewers demonstrate shorter gaze durations (Antes & Penland, 1981; de Graef, Christiansen & d'Ydewalle, 1990; Friedman, 1979; Henderson, Weeks, & Hollingworth, 1999; Hollingworth et al, 2001; Loftus & Mackworth, 1978) and naming latencies (Boyce & Pollatsek, 1992) on semantically consistent objects. Given the argument that memory guides prioritization of new objects without transient signals (Brockmole & Henderson,

2005a, 2005b, 2008), prioritization should depend on the critical object's semantic consistency to the extent that semantic consistency is related to memory. In support of Brockmole & Henderson's (2008) theory of separate mechanisms behind oculomotor capture and memory-guided prioritization, their results suggest that semantic consistency does not affect the efficacy with which transient onsets capture attention (oculomotor capture) but in the case of memory-guided prioritization new inconsistent objects are fixated sooner than new consistent objects, suggesting that attention prioritization without capture is a top-down memory-based phenomenon at least partially controlled by object identity and meaning (Brockmole & Henderson, 2008).

The first chapter of this thesis reviewed a large number of studies exploring the effects of action affordances and their interactions with visual perception. A group of experiments focused on interactions between pairs of objects that are semantically and functionally related and which can be normally used in combination to perform a common action. Objects' perceptual grouping based on such functional interactions and simulation of the actual interaction demonstrated one of the ways that action affordances can be pre-attentively used by the visual system to facilitate object recognition. Our first two experiments provided evidence supporting such findings and further demonstrated that such groupings are not based on exact metric positioning of an object with respect to the other object with which it can potentially be grouped, even though the same distance manipulations can have a measurable effect in post-perceptual descriptions. In another group of research there is a number of evidence for pre-attentive action affordance effects of single objects and even three dimensional shapes, based on their orientation

and their resemblance to a real object that can be manipulated (Tipper, Paul & Hayes, 2006; Symes, Ellis & Tucker, 2007). Such effects have been explained based on activation of pure motor representations compatible with such objects and have been suggested to take place in parallel with object identification processes.

Despite the evidence that automatic motor activations arise independently of an intention to act, it was also highlighted in our literature review that many of the experiments that have explored the relationship between motor activation and action affordances either made the functionality of the object relevant to the task or indirectly focused attention on it. It was therefore suggested that direct comparison between pre-attentive and post-perceptual effects of object action affordances would be useful to answer the question of how automatic and independent of intention to act action affordance effects are. A series of eye-tracking experiments were designed for this purpose and their results will be presented in this chapter. Moreover, because the combined result of Experiments 1.1 and 1.2 implied that the reported perceptual grouping was not based on the abstract nature of our line drawing stimuli, our research paradigm was extended towards using more realistic, in terms of our everyday experience, scenes. Based on the fact that the same grouping was not strictly bound to specific positioning of the objects combined in a functional pair (experiment 1.1), we were expecting to be able to also detect action affordance effects on real world scenes, despite their complexity.

Our second series of experiments were designed to test a number of hypotheses, both building upon these recent findings and utilizing the attentional prioritization paradigm

in real world scenes to address a novel approach to research on interactions between the perception and action systems. Because position and orientation are features of the on-line representation of objects generated during scene viewing (Aivar, Hayhoe, Chizk & Mruczek, 2005; Henderson & Hollingworth, 1998a; Hollingworth, 2004, 2006, 2007; Hollingworth & Henderson, 2002) we can use the positioning of appropriate objects (whose orientation is critical for their functionality) in real-world scenes to manipulate action affordances. Given that object functionality and action affordances can be manipulated independently of semantic manipulations in real-world scenes, we can use an attentional prioritization paradigm to test the effects of action affordance violations on visual perception. But, it is often the case that the critical object's positioning and action affordances have not been taken into account and adequately controlled for, in traditional semantic manipulation experiments, so our stimuli were designed for a better separation of these two factors.

The purpose of Experiment 2.1 was to develop a set of stimuli in which action affordance manipulations were independent of semantic manipulations. These stimuli could then be used in subsequent experiments to test how onsets of objects of different functional positioning, as well as online action affordance changes, are prioritized for viewing. In Experiment 2.2, we tested whether action affordance manipulations affect attentional prioritization when these critical objects are onset in real-world scenes, for both cases of oculomotor capture and memory guided prioritization, in a way similar to semantic manipulations. In Experiment 2.3 we tested whether a functional change in the positioning of a critical object in these real-world scenes also captures attention and

causes memory-guided prioritization of this object. In other words, we were interested to see whether another type of feature change such as the abolishment of the action affordance of a critical object in the scene, achieved by its change to an inappropriate orientation, would cause prioritization of this object, adding to the demonstrated prioritization in the case of colour changes (Matsukura, Brockmole & Henderson, 2009). In Experiment 2.4, we manipulated the direction of such orientation changes and as a consequence we tested the effects on attention modulation and deployment of eye-movements in the case of the creation of a functional positioning (useful action affordance) of the critical object in a scene from an original non-functional positioning. Finally, by comparing these last three experiments, we tested further the hypothesis of an independent mechanism triggering attention capture in the case of saccade changes and explored the role of visual memory in prioritization.

The aim of this series of experiments was to test action affordance effects of objects forming part of real world scenes, based solely on their positioning in the scene and stripped away of other influences such as semantic compatibility effects and interactions with other objects. Experiment 2.1 was designed to answer the question of whether action affordance effects can be independent of semantic consistency effects, based on our manipulation of object functionality through objects' positioning and orientation in a scene. We created a stimulus set with two versions of each scene and manipulated the orientation of a critical object in it. This manipulation introduced either an appropriate presentation of an object within the scene, or an inappropriate presentation where the usual action related to the critical object's functionality was no longer afforded. To

achieve this we used critical objects that have a specific functionality related to their proper orientation in the relevant context. For example, presentation of table prepared for serving dinner requires plates to be appropriately oriented with their base on the table and the surface to place food facing upwards. Inversion of a plate in such a scene, with its base facing upwards instead, violates its functionality as a plate because you can no longer place food on it.

In Experiment 2.1 we asked independent judges to rate the appropriateness of both semantic consistency of the object in relation to the rest of the scene and appropriateness of its positioning for its usual functionality. Brockmole and Henderson (2008) have recently created a similar stimulus set to test semantic consistency effects in object prioritization. We included these scenes along with our newly created stimulus set to compare the ratings along these two axes of semantic and action affordance consistency. If our action affordance manipulations are independent of semantic effects we would expect people's ratings to be significantly different when compared to the stimulus set used by Brockmole & Henderson (2008). In our stimulus set, we would expect the action affordance violation to impose lower action affordance ratings when compared to the baseline of the same objects in their appropriate orientation. Similarly in the Brockmole and Henderson stimulus set, we would expect the semantic violation to impose lower semantic consistency ratings when compared to the baseline of a semantically appropriate object in the scene. The difference between the two versions of each scene should be bigger for the semantic consistency ratings in the Brockmole and Henderson stimulus set and bigger for the action affordance consistency in our stimulus

set. If on the other hand no such difference arose, it would imply that action affordances were not manipulated independently of semantics in our stimulus set.

In Experiment 2.2 we used the scenes from the stimulus set we created to manipulate the action affordance of an object in a scene, as described for Experiment 2.1 above. Moreover we adapted the attentional prioritization paradigm (Brockmole 2005a, 2005b) to explore the effects of action affordances in prioritization. We used onsets of objects both correctly and incorrectly oriented in the display and we tested the speed of attentional prioritization by comparing the pattern of eye-movements with a baseline where the critical object was in view in the scene and not onset during scene viewing. This experiment could answer important questions regarding pre-attentive effects of orientation based action affordances. If motoric activations can pre-attentively affect object prioritization, we might expect faster prioritization in the case of objects that are onset in orientations that allow them to afford their normal functioning and which would entail such motoric activations, in comparison to objects whose orientations abolish the affordance for their normal functioning.

Object or scene inversion has also been used in some experiments to block automatic activation of top-down influences, such as global context effects (Intraub, 1984; Kelley, Chun, & Chua, 2003; Klein, 1982; Rock, 1974; Shore & Klein, 2000) or semantic knowledge about the function of shadows (Beck, 1969). For example a number of experiments concerning perceived lightness of stimuli in a shadow demonstrate that the same stimuli appear lighter to the observer when the stimulus (or the whole visual display) is presented up-right rather than when it is reversed (Adelson, 1993, 2000;

Beck, 1969; Gilchrist, 2006). Lightness refers to the *perceived reflectance* of a surface and therefore it constitutes the visual system's attempt to extract reflectance based on the luminance of a scene. A possible explanation is that a variation in luminance can be seen either as a shadow, or as a grey spot, depending on the apparent position of the surface (Beck, 1969). Inversion changes the apparent source of lighting that creates the shadow and leads to violation of the light-from-above assumption (Berbaum, Bever & Chung, 1984; Enns & Rensink, 1990; Gibson, 1950; Mamassian & Goutcher, 2001; Mamassian, Jentzsch, Bacon & Schweinberger, 2003; McManus, Buckham & Woolley, 2004; Rock, 1983).

Similarly, if motoric activations accompany recognition of an object positioned in a way that affords an action, violation of that critical positioning (such as a significant orientation change) would result in abolishment of its action affordance and it would block relevant motoric activations. Based on the similarity of our action affordance consistency manipulation with the previous semantic consistency manipulation in the same paradigm (Brockmole & Henderson, 2008) we would further expect these differences to become evident in memory guided prioritization, but not in oculomotor capture. Finally there is a possibility that action affordances and relevant motoric activations will not have an effect on object prioritization.

Moreover, evidence based on colour changes (Matsukura, Brockmole & Henderson, 2009) indicated that object prioritization can be based on feature changes and not only sudden onsets or offsets. In our Experiments 2.3 and 2.4 prioritization based on action affordance changes of a critical object were tested, manipulated through an important

feature of the critical object – orientation – that has been reported to be part of the important information bound on an object representation (Aivar, Hayhoe, Chizk & Mruczek, 2005; Henderson & Hollingworth, 1998a; Hollingworth, 2004, 2006, 2007; Hollingworth & Henderson, 2002). In these experiments we used the same attentional prioritization paradigm, as in Experiment 2.2, but instead of the an object onset in a scene either in its correct or an incorrect orientation, we introduced an orientation change altering the action affordance of a critical object that had already been part of the scene in the middle of the free-viewing period. In Experiment 2.3 we introduced the abolishment of the action affordance of the critical object in the scene, achieved by its change to an inappropriate orientation. In Experiment 2.4 we introduced the creation of a functional positioning (useful action affordance) of the critical object in a scene from an original non-functional positioning.

Based on the semantic consistency experiments (Brockmole & Henderson, 2008), any differences found between our conditions should be observed only in the case of memory guided prioritization and not in oculomotor capture, where object prioritization is based on motor transient related mechanisms. One possibility again would be that orientation changes are not sufficient to cause object prioritization, even though object prioritization was demonstrated in a similar case of colour changes. If, on the other hand, object prioritization can be caused by orientation changes, another possible result would be that this prioritization is affected by the direction of the orientation change of the critical object. Specifically, the orientation of the critical object before the orientation change might affect the encoding of the critical object in relation to a schema based on

the correct orientation that would allow the object its normal functioning. Therefore, the orientation of objects that were initially in view in an incorrect orientation may be more salient for the visual system and in this case prioritization of the object will be faster rather than when the same object is originally presented in a correct orientation.

Alternatively, faster prioritization might be observed in the case of objects that change from a correct to an incorrect orientation, which would imply that it is not the encoding of the object in memory that affects prioritization but pre-attentive processing of the created action affordance violation after the orientation change.

Finally, action affordance effects could be evident both pre-attentively in Experiment 2.2 as well as post-perceptually in Experiments 2.3 and 2.4 through the manipulation of the degree of violation from a given schema. Alternatively, action affordance effects could only be observed in one of the two variations of our paradigm, indicating that object orientation and functionality information is only relevant pre-attentively during object encoding and not post-perceptually or vice-versa.

Experiment 2.1

Given that similar attempts have been made to explore the effects in prioritization of the semantic consistency of the objects onset in a real world scene, as well as given our interest to test the simplest form of objects action affordances in a real world scene free from the confounding effects of other variables, we were interested in a way to manipulate action affordances alone. We tested single objects and not pairs of objects to avoid the effects of perceptual grouping and focused more on pure object affordances in

the complex visual display of real world scenes. We also wanted to isolate such action affordances of the critical object in the scene independently of semantic manipulations that were already found to play a role in prioritization, and these two factors are not always easy to separate as mentioned earlier and further analyzed later in this thesis. To consider how an intended manipulation of the semantic consistency of an object could unintentionally be confounded by action affordances, imagine the following example. According to a typical approach in manipulating semantic consistency of an object in a scene, an experimenter could change an original scene of a clock hung on the wall by substituting the clock with a frying pan. Such a substitution would violate relevant schemata not only because people do not usually hang a frying pan on their living room, but also because the action relevant schema related to the normal functioning of the frying pan requires it to be positioned on a vertical surface, rather than horizontally. To isolate action affordance effects, we constructed affordance-relevant appropriate and inappropriate versions of a visual scene by manipulating a critical object's orientation in order to allow for its normal use or to abolish the potential of an action compatible with its normal functioning. We took a picture of each configuration and created a stimulus set with two versions of each scene, where the critical orientation for an object's functioning was compatible with its use in the first and incompatible in the second version.

An online questionnaire was created to assess the appropriateness of this stimulus set created to use in a series of later eye-tracking experiments with regard to the action affordance – functional positioning manipulation. Participants were asked to rate two

aspects of the scene (semantics and action affordances) in a collection of real world scenes of this newly created stimulus set as well as another stimulus set of real world scenes created by Brockmole and Henderson (2008) for a previous semantic consistency manipulation in another experiment (see Appendix A for the participants' instructions). The first aspect of the scene to be rated referred to the semantic consistency of a critical object with regard to the rest of the scene, whereas the second one referred to its action consistency as defined by the appropriateness of its orientation for the normal functioning of the object.

Semantic consistency effects were manipulated in the Brockmole and Henderson (2008) experiment by swapping the place of two objects that were expected to be found in the context of the scene in their semantically compatible version, but when taken out of their context and positioned in the context of the other object they did not seem to belong in the scene. For example, a stuffed animal on a bed and a frying pan on a stove would be perfectly normal, but swapping their place and presenting a frying pan on a bed or a stuffed animal on a stove would not be semantically consistent with the context of that scene. By comparing ratings for these two aspects of the scenes between the two stimulus sets, we were interested in how well action affordances can be separated from semantics. Similarly, action affordance effects were manipulated in the stimulus set created for that purpose by imposing the maximum rotation to an object that would abolish its normal function, such as rotating a glass with its open top facing the surface of the table rather than facing upwards.

People were asked to rate these two stimulus sets which had been created for a different purpose each – the first to manipulate semantic consistency, hereafter named “semantic consistency stimulus set”, and the second to manipulate action affordance, hereafter named “action consistency stimulus set”- along both critical dimensions of semantic and action consistency. The mean rating for each object at each stimulus set and consistency configuration (semantic for the old stimulus set and functional for the new) was computed on each of the two consistency axes. To test the efficiency of the manipulation for every specific scene as compared to the rest of the stimulus set, the difference in ratings between the consistent and inconsistent version was plotted and tested with a paired samples t-test for each critical object (at an item per item basis). At the same time, to distinguish whether the semantic manipulation was more effective in the semantic consistency stimulus set and the action affordance manipulation was more effective in the action consistency stimulus set, the mean difference in ratings within the compatible and incompatible version of the scenes within each stimulus set was analyzed by a mixed model ANOVA and compared with the mean rating of the other stimulus set by a paired samples t-test (at a group level). The difference in ratings in the semantic consistency question acted as a control for the stimulus set where the manipulation was intended to define the functionality of the critical object and the difference in ratings in the action affordance question was used as a control for Brockmole & Henderson’s (2008) stimulus set where the manipulation was intended to define the semantic consistency of the critical object.

Method

Participants. Fifty volunteers (recruited online) participated in the research (40 female, 10 male, mean age = 25.8 years). All the participants were naïve to the experimental hypothesis.

Table 2: A list of the 30 critical objects in our Action Consistency stimulus set.

Action Consistency Stimulus Set			
1	Bag	16	Microphone
2	Bin	17	Mixer
3	Bucket	18	Mustard
4	Candle	19	Pan
5	Chair	20	Piggy bank
6	Clock	21	Plate
7	DVD	22	Reading lamp
8	Fan	23	Screen
9	Glass	24	Shower
10	Guitar	25	Soap dispenser
11	Iron	26	Teacup
12	Juice blender	27	Toaster
13	Keyboard	28	Train
14	Lamp shade	29	TV
15	Laptop	30	Water fridge

Stimuli and Apparatus. Two stimulus sets were used in this experiment. The first was taken from Brockmole and Henderson (2008). This stimulus set consisted of 60 colour photographs depicting 30 everyday real world scenes. Each scene was photographed twice with either a semantically consistent or inconsistent critical object (Figure 11, panels A and B respectively). The second stimulus set also consisted of 60 different colour photographs depicting 30 scenes. In the case of this second stimulus set created for this series of experiments, scenes were photographed with a critical object (Table 2) oriented in a manner appropriate for use (Figure 11, panel D) or in an

inappropriate orientation (e.g. upside down; Figure 11, panel C). The incorrect orientation abolished the potential for using or acting normally upon the object. For ease of exposition, we will refer to inappropriate objects (semantic stimulus set) and incorrectly oriented objects (action affordance stimulus set) as inconsistent objects and all appropriate stimuli as consistent objects, when generalising between the manipulations in both stimulus sets.



Figure 11: An example scene for each consistency version of the manipulations regarding semantic consistency (Brockmole & Henderson, 2008; top) as well as the functionality and action affordance (bottom) of the critical object in the scene. Panels A and D show an example of semantically and functionally consistent objects whereas panels B and C show semantically and functionally inconsistent objects respectively. The yellow square marking the critical object was used as a reference of the critical object for the participant.

Our data (consistency ratings for stimuli from both stimulus sets) were collected through an online questionnaire set up for this purpose (for details see design and procedure below). Participants could access the questionnaire via a website; therefore stimuli were presented on the participants' own computers and ratings were given at their own pace, since there was no response time recording in the measures of interest for the specific experiment.

Design and procedure. Participants viewed all 120 photographs (each of the 60 scenes was presented twice so that both consistent and inconsistent versions of each critical object were viewed by each subject) and rated critical objects along two consistency axes (semantic and functional-action affordances).

For each scene, the critical object was denoted by a yellow rectangle surrounding it. Participants rated these objects along two dimensions. First, they were asked "how appropriate is the object in relation to the context of the image, as defined by the rest of the objects comprising the scene". They were then asked "how appropriate is the orientation / spatial layout of the object when compared to its optimal orientation in the image if you wanted to use it". The first question pertained to the appropriateness of the object within the context of the scene, whereas the second pertained to the functionality of the object with regard to physical interaction. All ratings were given on a 1-7 Likert scale. In addition to these ratings, demographic information including age, sex, handedness, whether their native language is English and whether they use glasses or contact lenses were provided by each participant.

Results

Semantic Consistency Scale: Objects from scenes in both stimulus sets were rated for semantic consistency (Figure 12). These ratings were submitted to a 2 (Stimulus Set) \times 2 (Consistency) repeated measures ANOVA. A main effect of Consistency was observed [$F(1, 29) = 1306.999, p < .001$] as inconsistent objects ($M_I = 4.131$) were, on average, given lower ratings than consistent objects ($M_C = 6.591$). A main effect of Stimulus Set was also observed [$F(1, 29) = 1409.392, p < .001$] with stimuli in the action consistency stimulus set ($M_{Act} = 6.626$) receiving generally higher ratings than stimuli in the semantic consistency stimulus set ($M_{Sem} = 4.096$). Most importantly, an interaction between Stimulus Set and Consistency was observed [$F(1, 29) = 990.311, p < .001$]. Consistent objects received similar ratings across the stimulus sets ($M_{CAct} = 6.729, M_{CSem} = 6.453$). However, inconsistent objects were given significantly higher ratings ($t = -52.370, df = 29, p < .001$) in the action consistency stimulus set ($M_{IAct} = 6.523$) than in the semantic consistency stimulus set ($M_{ISem} = 1.739$), proving the efficiency of the independence of the action affordance manipulation from semantic influences.

A more meaningful way of presenting this interaction is that in the semantic consistency stimulus set semantically consistent objects were rated significantly higher than semantically inconsistent objects ($M_{dS} = 4.71$). For the action affordances consistency stimulus set, ratings were identical across the correct and incorrect orientations ($M_{dA} = 0.21, n.s.$). At the question of rating the semantic consistency of the critical object the difference between the consistent and the inconsistent version of the

scenes was significantly higher in the semantic consistency stimulus set than in the action consistency stimulus set ($t = 31.492$, $df = 29$, $p < .001$).

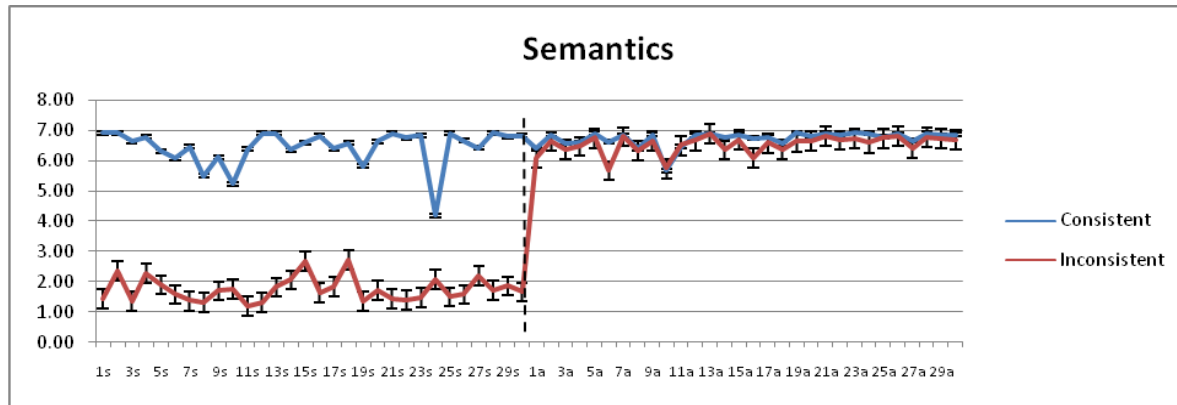


Figure 12: Semantic consistency ratings for both versions of each real world scene, from both stimuli sets. The first 30 data points belong to the semantic consistency stimulus set and the last 30 in the action consistency stimulus set. The two stimulus sets are separated by the dashed line in the middle of the graph. The success of the semantic consistency manipulation is obvious in the former stimulus set as well as lack of semantical differences in the latter one.

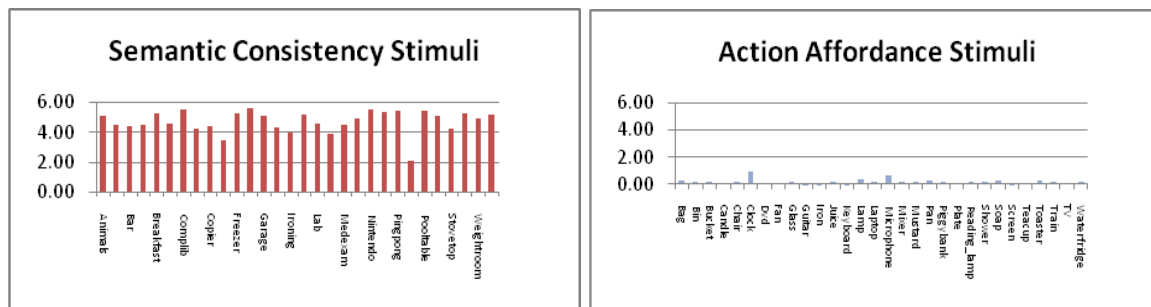


Figure 13: Mean differences in the semantic consistency ratings for each scene in the semantic consistency and the action consistency stimulus sets.

To assess the consistency of this pattern across the individual stimuli, we computed a rating difference score for each stimulus which simply subtracted the score given to inconsistent versions of each scene from the rating given to the consistent version, in both the semantic and action consistency stimulus sets. Bonferroni corrected paired samples t-tests revealed that this difference was significant for each of the scenes in the semantic consistency stimulus set ($p < .001$, critical value $p = .0017$) but the pictures in

the action affordances stimulus set showed no differences (all p 's > .003) in semantic ratings⁷ (Figure 13; see Appendix B for details of the t-test for each item).

Action Affordance Consistency Scale. Action affordance consistency ratings (see Figure 14) were submitted to a 2 (Stimulus Set) \times 2 (Consistency) repeated measures ANOVA. A main effect of Consistency was observed [$F(1, 29) = 482.443, p < .001$] as inconsistent objects ($M_I = 3.508$) were, on average, given lower ratings than consistent objects ($M_C = 6.237$). A main effect of Stimulus Set was also observed [$F(1, 29) = 19.681, p < .001$] with stimuli in the action consistency stimulus set ($M_{Act} = 4.620$) receiving generally lower ratings than stimuli in the semantic consistency stimulus set ($M_{Sem} = 5.125$). Importantly, an interaction was observed [$F(1, 29) = 67.125, p < .001$]. Consistent objects received similar ratings across the stimulus sets ($M_{CAct} = 6.444, M_{CSem} = 6.029$). However, inconsistent objects were given substantially lower ratings ($t = 8.392, df = 29, p < .001$) in the action consistency stimulus set ($M_{IAct} = 2.796$) than in the semantic consistency stimulus set ($M_{ISem} = 4.220$), proving the efficiency of the action consistency manipulation.

A more meaningful way of presenting this interaction is that in the action consistency stimulus set normally oriented objects were rated significantly higher than abnormally oriented objects ($Md_A = 3.65$). For the semantic consistency stimulus set smaller random

⁷ Only an object from this stimulus set showed a significant difference between its compatible and incompatible versions (clock: $t = 3.58, df = 49, p < .001$). But this difference was much smaller than the minimum difference in the semantic consistency stimulus set, so it was deemed that there was no reason for it to be excluded from the action consistency stimulus set.

differences were observed between semantically consistent and inconsistent versions ($Md_s = 1.80$). At the question of rating the action consistency of the critical object the difference was significantly higher in the action consistency stimulus set as compared to the semantic consistency stimulus set ($t = 8.195$, $df = 29$, $p < .001$).

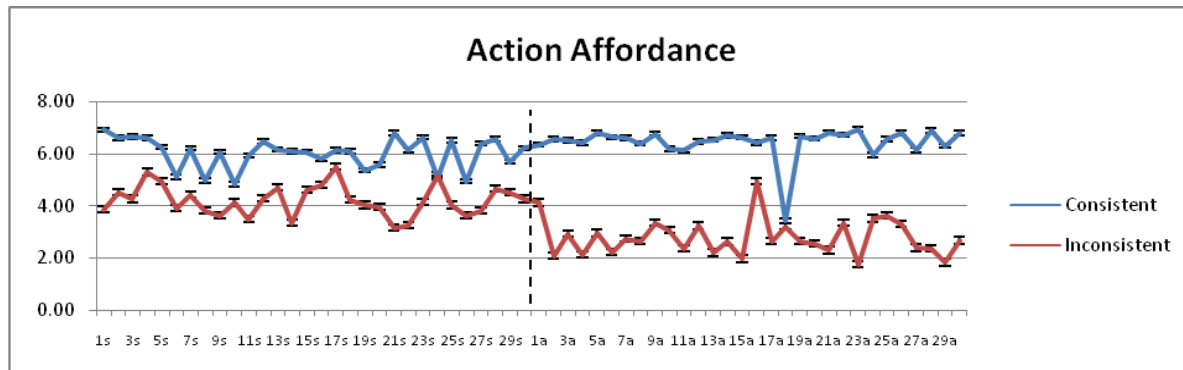


Figure 14: Action affordance consistency ratings for both versions of each real world scene, from both stimuli sets. The first 30 data points belong to the semantic consistency stimulus set and the last 30 in the action consistency stimulus set. The two stimulus sets are separated by the dashed line in the middle of the graph. The action affordance consistency manipulation is obvious in the latter stimulus set; in the semantic consistency stimulus set there are some random but not consistent differences, as action affordance consistency was not taken into account at its creation.

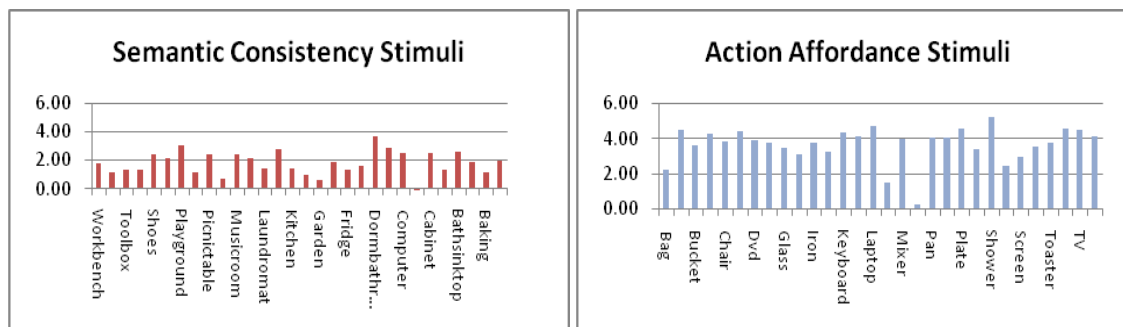


Figure 15: Mean differences in the action affordance consistency ratings for each scene in the semantic consistency and the action consistency stimulus sets.

To assess the consistency of this pattern across the individual stimuli, we computed a rating difference score for each stimulus which simply subtracted the score given to inconsistent versions of each scene from the rating given to the consistent version, in both the semantic and action consistency stimulus sets. Bonferroni corrected paired

samples t-tests revealed that this difference was significant for each of the scenes in the Action Affordances Stimulus Set ($p < .001$, critical value $p = .0017$, except for one object). Twenty-six out of the thirty pictures in the semantic consistency stimulus set also revealed significant differences in the action affordance manipulation (Appendix B), but these differences were on average much smaller than the Action Affordance Stimulus Set (Figure 15).

Discussion

As a conclusion, analysis of the data from the online questionnaire revealed that the action affordance manipulation in our stimulus set was successful and independent of any confounding from semantics. The mean rating of the action affordance difference between the compatible and incompatible versions was significantly higher in the action consistency stimulus set compared with the semantic consistency stimulus set. On the other hand, the mean rating of the semantic consistency difference between compatible and incompatible versions was almost zero for our action consistency stimulus set, significantly lower of course than the mean difference in the ratings for the semantic consistency stimulus set.

When we examine the mean difference in ratings of individual items (rated on a 7-point Likert scale) within each stimulus set we see that for the action consistency

stimulus set they ranged between 2.22⁸ and 5.18 in the action affordances axis and between 0 and 0.96 in the semantics axis. For the semantics consistency stimulus set the mean difference in ratings of individual items ranged between 2.10 and 5.61 in the semantics axis but also between 0.1 and 3.64 in the action affordances axis. These ratings of action affordance differences within the semantic consistency stimulus set reveal that although Brockmole & Henderson's (2008) manipulation did not take into account functional positioning and action affordances of the critical object, this factor was unaccounted for and was confounding the distance between the compatible and incompatible version of each critical object at a different degree. A number of the scenes used by them (26 out of 30) included small action affordance differences between the two versions in addition to semantic differences. A few of the objects selected for the creation of semantically inconsistent scenes diverted from the schema regarding the optimal orientation for the object's functionality at a bigger or lesser degree.

Nevertheless, our manipulation in the Action Consistency Stimulus Set adequately manipulated action affordances of the critical object and this manipulation was totally independent of semantics effects. In other words our manipulation was more efficient in distinguishing action affordance from semantic consistency effects, as compared to the addition of some minor action consistency effects in the semantic manipulation of Brockmole & Henderson (2008). Of course action affordances were not of interest for

⁸ Two of the stimuli with mean difference in ratings lower than 2.22 were excluded from the consequent experiments as less effective action affordance manipulations compared with the rest of the stimulus set.

the specific experiment and there is no indication that they had a significant effect in their findings, especially since these random differences are quite smaller than in the action consistency stimulus set.

EXPERIMENT 2.2

Sudden onsets lead to fast attention capture, be they in simple arrays of objects or in real world scenes (Boot, Krammer & Peterson, 2005; Brockmole & Henderson, 2005a; Irwin, Colcombe, Kramer & Hahn, 2000; Theeuwes, Kramer, Hahn & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin & Zelinski, 1999; Yantis & Jonides, 1984). Also, experiments by Brockmole and his colleagues (2005a, 2005b, 2008, 2009) demonstrated that the degree of prioritisation given to an onset differs depending on whether the onset occurred during a saccade or within a fixation, with faster and greater attentional prioritization in the case of fixation changes which are accompanied by motion transients. Finally, manipulation of the semantic consistency of the onset object within the scene was found to affect the degree to which new objects appearing in the scene are prioritized for viewing in the case of onsets within a saccade, but not within a fixation. During a saccade change, new semantically inconsistent objects were fixated sooner than new consistent objects (Brockmole & Henderson, 2008).

The aim of the present experiment was to investigate whether action affordances associated with an onset in a scene can modulate the degree of prioritization it receives. Specifically, we could expect that, given that our action affordance manipulations had similar effects to schema violations with semantic consistency manipulations, memory

guided prioritization and the deployment of eye-movements would be similarly affected by the orientation sensitive action affordances of these critical objects onset in real-world scenes. Evidence about the encoding of orientation related information for object representations and the inclusion of action affordance and functionality information in relevant schemata was provided in the literature review in our first chapter. Moreover, except for the evidence for the role of action affordances in the perceptual grouping of objects that can be combined in a common action, which was also covered in the literature review and further explored by our first two experiments in the second chapter of the thesis, experiments regarding physical object affordances were reviewed. In such experiments it has been argued that motoric representations of the action that an object affords are activated automatically and in parallel with the process of object recognition. Such activations could be used by the visual system to facilitate perception and should therefore have measurable behavioural effects.

In our object prioritization paradigm, such activations could have fast enough effects to facilitate prioritization of correctly oriented objects and would be absent in the case of incorrectly oriented objects. Such effects should be evident in memory guided prioritization, but not necessarily in transient signal dependent oculomotor capture, in agreement with the semantic consistency experiment (Brockmole & Henderson, 2008). According to such theories, we should expect a difference in memory guided prioritization in the two onset conditions (correct vs. incorrect orientation). As for the direction of this difference specifically we could expect two different outcomes: If orientation based action affordances lead to motoric activations related to the critical

object only in the case that the object is onset in a correct orientation, we would expect faster prioritization in the case of correctly oriented objects; incorrectly oriented objects would not lead to motoric activations relevant to their functionality, so such information would not contribute in their prioritization. If, on the other hand, memory-guided prioritization is based on the mismatch between the action affordance activation from an object and the action-relevant schema of its normal orientation, incorrectly oriented objects could lead to greater prioritization because they differ more from the schema of the optimal orientation for their normal use. Finally, lack of a difference between the two onset conditions in memory guided prioritization would provide evidence against pre-attentive effects of action affordances.

To answer this question we compared attentional prioritization between two similar experimental groups with the only difference of when the new object would be onset in the scene. Onset Condition (saccade vs. fixation) was used as a between subjects variable. Also, a control no-onset condition was used as a baseline against which fixation probabilities after the appearance of a new object could be compared, in accordance with the methodology of Brockmole and his colleagues (2005a, 2005b, 2008, 2009). Within each of the experimental groups, half of the critical objects, whether onset or in view all along the trial, were displayed in the correct way to allow normal action and the other half in an incorrect way to abolish their normal use.

Moreover, except for the speed and degree of prioritization, the design of the specific experiment and the richness of the information gathered through the eye-tracking data, allowed us to test a number of more generic influences of action affordances on the

nature and the distribution of eye-movements. Both the control condition where no onsets were present, and the part of the trial after the onset in the experimental conditions, provided us with a recording of a number of important measures related to eye-movement behaviour. A large amount of data related to the density (the absolute number) of fixations and the time spent on the critical object as well as the duration of the first fixation on the critical object or the times that an observer went back and forth at looking at it provide a great insight into real-time cognitive processing related to object recognition. The effects of action affordances on such measures, which have been previously explored in juxtaposition with processing of higher level information such as semantic inconsistencies, can provide a crucial basis of the generic influences of action affordances' modulation of eye-movement behaviour.

Method

Participants. Thirty-six volunteers recruited from Edinburgh University's career services website participated in the research for an honorarium of £4 (26 female, 10 male, mean age = 23.14 years). All the participants had normal or corrected to normal vision (19 normal, 17 glasses/contacts) and were naïve to the experimental hypothesis. Participants were randomly assigned to one of the three experimental or control groups (details in the design and procedure section).

Stimuli and Apparatus. Stimuli consisted of colour photographs of 30 everyday real world scenes. For each scene, a critical object was selected whose orientation was critical for its normal use (see Table 3). Three photographs of each scene were taken.

Each scene was photographed with its corresponding critical object in its correct orientation (appropriate for use; Figure 16, panel B) and in an incorrect orientation (e.g. upside down; Figure 16, panel D). The incorrect orientation abolished the potential for using or acting upon the object. A third photograph of each scene was also taken with the critical object removed (Figure 16, panels A and C). Photographs were edited where necessary to eliminate minor differences in shadowing or object placement that may have occurred between the two shots. These scenes used in the current and later eye-tracking experiments were the same scenes that were used to construct the action consistency stimulus set in Experiment 2.1, where the efficiency of the action affordance manipulation and its independence from semantic effects were tested.

Table 3: A list of the 30 critical objects in the scenes used in experiment 2.2.

Action Consistency Stimulus Set			
1	Bag	16	Microphone
2	Bin	17	Mixer
3	Bucket	18	Mustard
4	Candle	19	Pan
5	Chair	20	Piggy bank
6	Clock	21	Plate
7	DVD	22	Reading lamp
8	Fan	23	Screen
9	Glass	24	Shower
10	Guitar	25	Soap dispenser
11	Iron	26	Teacup
12	Juice blender	27	Toaster
13	Keyboard	28	Train
14	Lamp shade	29	TV
15	Laptop	30	Water fridge

Stimuli were presented on a 21” ViewSonic (P227f) CRT monitor with a resolution of 1024 x 768 pixels and a screen refresh rate of 120 Hz. Participants were seated at a distance of 81 cm from the computer monitor, with chin and forehead rests keeping

viewing distance constant. Stimuli were presented at a resolution of 800 x 600 pixels. Throughout each trial, the spatial position of each participant's right eye was sampled at a rate of 1000 Hz by an EyeLink 2K eye-tracking system (SR Research, Ltd., Mississauga, Ontario, Canada) running in pupil and corneal-reflection mode, which resulted in an average spatial accuracy of 0.15°. An eye-movement was classified as a saccade if its amplitude exceeded .2° and either (a) its velocity exceeded 30 degs/sec or (b) its acceleration exceeded 9500 degs/sec.



Figure 16: An example scene for the photographs used in this study before (A, C) and after (B, D) the onset. In the top the critical object is onset in a correct whereas in the bottom in an incorrect orientation. The yellow square marking the critical object is for reference only here and was not part of the experimental stimuli.

Design and Procedure. The experiment employed a 3 x 2 mixed-factor design. The between subjects factor was Onset Condition (no onset, saccade onset or fixation onset) and the within subjects factor was Object Orientation (correct vs. incorrect).

The participants took part in a computer-based mock memorization task while their eye-movements were recorded. Participants were instructed to study all 30 scenes for 10 seconds each for a subsequent memory test. Their eye movements were recorded during scene viewing. No memory test was actually administered as the critical manipulations occurred while observers were studying the scenes. Participants were randomly allocated to one of 3 onset conditions. In the saccade condition the critical object was onset during a saccade whereas in the fixation condition it was onset during a fixation. In the control condition the critical object was present from the beginning of the trial (i.e. no onset was present). Within each onset condition the critical object was presented in either the correct (on half the trials) or incorrect orientation (on the other half). In the saccade and fixation conditions all the trials started with the photograph with the critical object absent and this was replaced with the one with the object either in the correct or incorrect orientation, to achieve the phenomenological experience of the onset. In the control condition the same photograph with the critical object either in correct or incorrect orientation remained on view for the whole duration of the trial.

The experimental session began by calibrating the eye tracker for every participant. Calibration was then monitored throughout the experiment and re-adjusted if necessary. Each trial started with the participant looking at a dot in the centre of the screen. A button press served to begin a drift correction procedure as well as present the scene

image. After the button press a scene was displayed for 10 seconds. The onset, if applicable, occurred during either a saccade or a fixation according to the experimental condition to which the participant was allocated. In the saccade condition this change in the display image happened during the first saccade executed after 5 seconds had elapsed from the beginning of the trial so that the eyes were still moving during the change. For the fixation condition, the change happened 100 msec after the onset of the first saccade executed after 5 seconds of scene viewing. This allowed enough time for this saccade to terminate but not enough for another one to commence, thus allowing the change to happen when the eyes were still. As mentioned earlier, half the images were randomly assigned to be onset in the correct orientation and the other half in the incorrect orientation for each participant, so that every participant viewed equal number of scenes from both action affordance consistency conditions.

Results

Similar analyses as in previous experiments were employed (see Brockmole & Henderson, 2005a, 2005b; Matsukura, Brockmole & Henderson, 2009). First, the probability of the critical object being fixated after its onset was compared with the probability it was fixated when the object was in view all along, to determine if this probability surpasses chance. The speed of prioritization was also considered, to determine whether prioritization based on oculomotor capture would be evident sooner than that based on memory guided prioritisation. Finally we wanted to see whether action affordance (orientation) would modulate any of these effects.

A region of interest was drawn around each critical object to allow for estimation of the probability of fixation on the specific object. The region of interest was a rectangle whose size was the minimum required to surround the critical object. Each of the participant's fixations during a trial was coded with a 0 if it fell outside this area of interest and a 1 if it fell within it. Because we are interested in characterizing the initial prioritization of a new object soon after its appearance in a scene, analyses were confined in the first 4 fixations after the onset, in accordance with the methodology in Brockmole & Henderson's previous experiments (2005a, 2005b).

The term "ordinal fixation position", which can be defined as the temporal order of fixations after the onset, is used to refer to each of these fixations. For fixation changes, the first ordinal fixation position therefore refers to the fixation immediately following the onset and the first fixation that could be selected after the new object appeared, the second ordinal fixation position refers to the second fixation following the onset and so on. For the saccade condition, it would refer to the order of the fixations immediately following the pre-planned fixation taking place after the change which was triggered during the preceding saccade. This way, the average probability of fixating the area of interest for any given ordinal fixation position within the trial could be computed. The regions of interest for each scene with the critical object either in correct or incorrect orientation were closely equated because, despite the orientation rotation, it was the same object in both cases that they enclosed.

The measure of interest in the control and the onset conditions in the paradigm used in these experiments was mainly the speed of prioritization of the critical object. This

measure can be obtained from calculating the probability with which the critical object is fixated for the first time at each ordinal fixation position. Therefore, first look probabilities can be used as a measure of the speed with which prioritization of the critical object happens. Mean fixation probabilities are a measure of both first looks and refixations at a critical object at any given ordinal fixation position and as a result, they provide only a general sense of the speed with which new objects are prioritized for viewing. Mean fixation probabilities however can be used as an indication of the allocation and distribution of attention. In addition to the question whether prioritization is affected by the orientation of the critical object, mean fixation probabilities will be also analysed for the onset conditions to denote whether attention, once directed to the critical object through prioritization, remains at incorrectly oriented objects for longer as compared to correctly oriented ones.

As mentioned earlier, a number of additional analyses were carried out based on both the whole duration of the trial for the control condition and the onset period of the trial (the half of the trial after the critical object was onset) for the fixation and saccade conditions. Differences between correctly and incorrectly oriented objects in the number of fixations and the amount of time spent of them might be representative of differences in the memory encoding or representation of objects based on their action affordance. The role of both visual short term memory and the input from long term memory schemata related to the functionality of an object or a pair of objects were discussed extensively in the previous chapters. As a result, the question of whether there are differences in the memory encoding of objects of correct action affordances as compared

to action affordance violations is of great interest for the question of the effects of action affordances on perception. Moreover, it is well known from the relevant literature that semantic inconsistencies affect eye-movements (e.g. Vo & Henderson, 2009), for example by increasing fixation durations. Also, increased foveal processing is known to benefit memory encoding (Henderson & Ferreira, 2004). Therefore, action affordance violations could have similar influences and modulate eye-movements, so it is important to test such generic effects of action affordances on eye-movements, which by definition can consequently affect memory encoding. A number of measures included in the data collected during the recording of eye-movements were compared between correctly and incorrectly oriented objects with a number of within-subjects t-tests. Such measures included fixation dwell times and the percentage of the trial spent on the critical object, the fixation count as well as the percentage of the total fixations in the trial that were directed to the critical object, the first run dwell time and the run count of the times the area of interest was entered and left.

NO-ONSET CONDITION (BASELINE)

As a control, fixation probabilities on the critical objects were determined when no onset was present. The first 4 fixations from the beginning of the trial were used to

estimate fixation probabilities in the control group condition because these fixations represent the observers' first opportunity to look at the critical objects.⁹.

A 2 (Object Orientation) x 4 (Ordinal Fixation Position) mixed model analysis of variance (ANOVA) considered the probability with which gaze was directed to the critical objects. Results are illustrated in Figure 17. The main effect of Object Orientation was not significant, although there was a trend for incorrectly orientated objects to attract more fixations than correctly orientated objects [$F(1, 11) = 3.194$, $p = .101$]. The baseline mean fixation probability was 13.1% for the incorrectly orientated and 9.3% for correctly orientated objects. Analysis revealed a main effect of Ordinal Fixation Position [$F(3, 33) = 5.255$, $p = .004$] but this was an artefact of our choice of the beginning of the trial to be used as a baseline to compare mean fixation probabilities after onsets. The 1st ordinal fixation position had lower fixation probabilities ($M_1 = 6.4\%$) than the 3rd and 4th ordinal fixation positions ($M_3 = 14.2\%$, $p = .019$; $M_4 = 15.8\%$, $p = .027$). These differences arose because later ordinal fixation positions are a combination of first looks and refixations (e.g. participants move their eyes to the region of interest, then move away, but return again to the critical area) whereas the very first ordinal fixation position in the trial consists by default of the first look probability only

⁹ A matching based on absolute time using the first 4 ordinal fixation positions from the last 5 seconds of the control condition were also checked anyway and the results did not differ.

and does not include refixations¹⁰. The Object Orientation by Ordinal Fixation Position interaction did not reach significance [$F(3, 33) = 1.984, p = .136$].

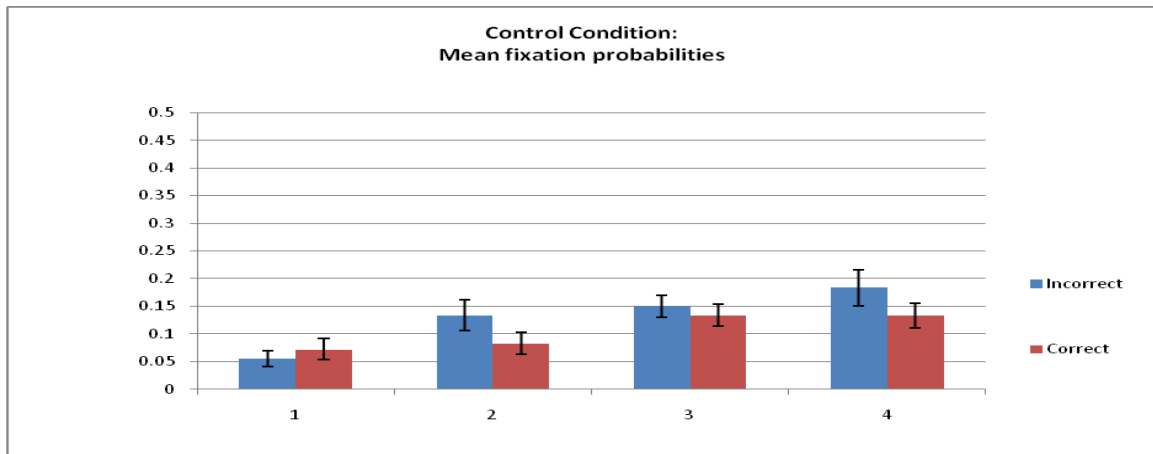


Figure 17: Mean probabilities of the critical object being fixated at any of the first four ordinal fixation positions of the trial in the control condition, used as a baseline for the onset time window of the experimental conditions. Error bars represent 95% confidence intervals.

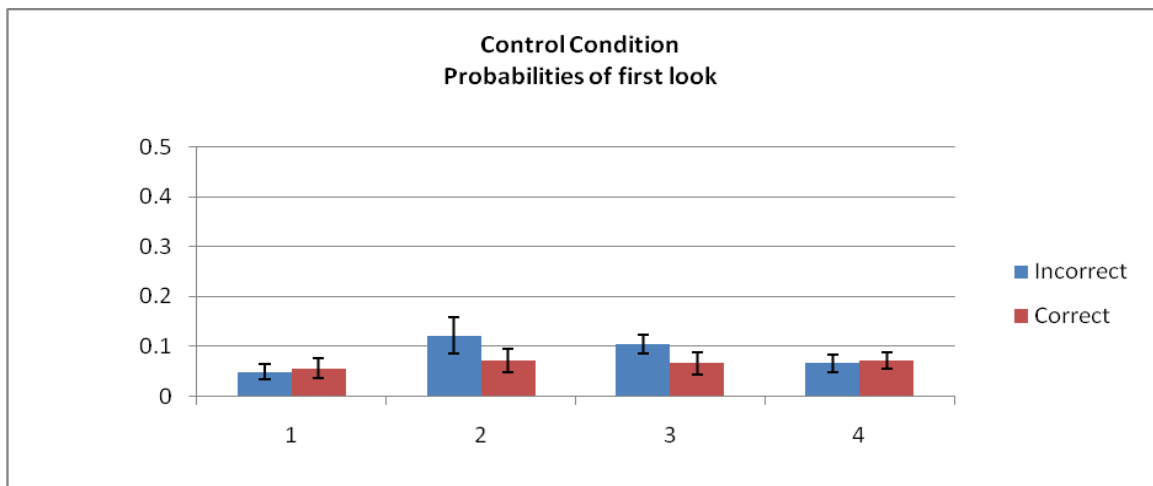


Figure 18: Mean probabilities of the critical object being fixated at any of the first four ordinal fixation positions of the trial in the control condition, used as a baseline for the onset time window of the experimental conditions. Error bars represent 95% confidence intervals.

¹⁰ This main effect is not significant when we check the first 4 ordinal positions from the time window of the last 5 seconds of the trial (equivalent to the onset period of the experimental condition) where refixations are also carried over from previous ordinal fixation positions.

A more “clean” measure that showed that there were no default differences in the no-onset conditions was the probability of first look, where no significant differences were found on any of our factors across the representative 4 ordinal fixation positions of choice (Figure 18). The baseline probabilities of first look were 8.6% for incorrectly oriented and 6.7% for correctly orientated objects. The results of restricting analysis only to the probability of first looking at the critical object in each of the four ordinal fixation positions indicated that the above effects were indeed driven by refixations (more refixations in the incorrect orientation condition and more refixations at later ordinal fixation positions).

ONSET CONDITIONS: Probability of first look.

The results of the control condition that mean fixation probability distributions may be influenced by post-selection mechanisms related to object recognition verify the hypothesis that analysis of first look probability is more critical in answering our main question of interest for the role of object functionality (orientation) in the speed of prioritization. For example, when we consider mean fixation probabilities, incorrectly oriented objects may receive more fixations (i.e. attention) not because they are more likely to be prioritized, but because they are more likely to retain attention once they are fixated. These biases were less of a concern in Brockmole and Henderson (2005) where all objects were consistent with the scene and presented in a correct manner and so they did not specifically analyse their data in a similar manner (although they did assess prioritization speed based on conditional probabilities).

A mixed model analysis of variance (ANOVA) was conducted on the probability of first looking at the critical area after the onset as a function of Object Orientation (correct vs. incorrect), Ordinal Fixation Position (1-4) and Onset Condition (fixation vs. saccade). In other words, first look probabilities were filtered so that they do not include refixations but only show the probability that the critical object was fixated for the first time at each of the 4 ordinal fixation positions of interest. The results of this analysis are illustrated in Figure 19.

The 3-way ANOVA revealed a significant main effect of Onset Condition [$F(1, 22) = 79.936, p < .001$], with a near doubling in the probability of first fixating changes that occurred during a fixation ($M_F = 22.9\%$) as compared to changes that occurred during a saccade ($M_S = 12.2\%$) within our window of analysis (i.e. within the first 4 fixations post onset). This finding demonstrated that attention capture is stronger in the presence of a motor transient signal. There was also a main effect of Ordinal Fixation Position [$F(1.3, 28.7) = 64.555, p < .001$, Greenhouse-Geisser correction] with each ordinal fixation position having significantly lower first look probability compared to the previous one, as planned comparisons revealed ($M_1 = 41.3\% > M_2 = 20.9\% > M_3 = 5.9\% > M_4 = 2.2\%$, $p < .003$). It seems that in our paradigm prioritization happens quickly and decreases gradually at later ordinal fixation positions, especially during the first two fixations after the onset, a result that parallels previous experiments from Brockmole and his colleagues (2005a, 2005b, 2008, 2009).

Finally, and most importantly, there was a significant interaction between Ordinal Fixation Position and Onset Condition [$F(3, 66) = 16.979, p < .001$], with the slope of

the change being steeper for the fixation condition (indicating stronger and faster prioritization in the first ordinal fixation position) rather than the saccade condition (

Table 4), in agreement with the original Brockmole and Henderson (2005a, 2008) experiments. This was verified by planned comparisons which revealed that in the case of onsets within a saccade probabilities of first fixating the onset within the first two ordinal fixation positions were significantly different from the last two ($p < .012$) but not from one another ($t = 1.553$, $df = 11$, $p = .153$)¹¹. The same differences between ordinal fixation positions were recorded in the case of onsets within a fixation. The first two ordinal fixation positions were significantly different from the last two ($p < .001$) but in this case, the 1st ordinal fixation position also had significantly higher probability of first looking at the critical object compared to the 2nd one ($t = 3.871$, $df = 11$, $p = .003$)¹². The difference between the 3rd and 4th ordinal fixation positions was also significant in the case of fixation onsets ($t = 2.794$, $df = 11$, $p = .017$), whereas in saccade onsets the difference only showed a trend for significance ($t = 1.918$, $df = 11$, $p = .081$).

¹¹ Specifically the probability of first look in the 1st ordinal position ($M_{1S} = 23.3\%$) was significantly higher than both the 3rd ($M_{3S} = 6.9\%$, $t = 3.467$, $df = 11$, $p < .005$) and 4th ($M_{4S} = 3.8\%$, $t = 5.109$, $df = 11$, $p < .001$) ordinal fixation positions. The probability of first look was significantly higher in the 2nd ordinal fixation position ($M_{2S} = 14.9\%$) as compared to both the 3rd ($M_{3S} = 6.9\%$; $t = 2.988$, $df = 11$, $p = .012$) and 4th ($M_{4S} = 3.8\%$; $t = 4.263$, $df = 11$, $p = .001$) ordinal fixation positions as well, but it was not significantly different from the 1st ordinal fixation position ($t = 1.553$, $df = 11$, $p = .153$).

¹² Specifically the 1st ordinal fixation position had significantly higher probability of first looking at the critical object ($M_{1F} = 59.3\%$) from both the 3rd ($M_{3F} = 4.9\%$, $t = 11.084$, $df = 11$, $p < .001$) and 4th ($M_{4F} = 0.6\%$, $t = 13.221$, $df = 11$, $p < .001$) ordinal fixation positions. Also first look probability in the 2nd ordinal fixation position ($M_{2F} = 26.9\%$) was significantly higher than the 3rd ($t = 5.081$, $df = 11$, $p < .001$) and 4th ($t = 6.574$, $df = 11$, $p < .001$). In this case though, in addition to the previous differences, the 1st ordinal fixation position had significantly higher probability of first fixating the critical object than the 2nd one ($t = 3.871$, $df = 11$, $p = .003$).

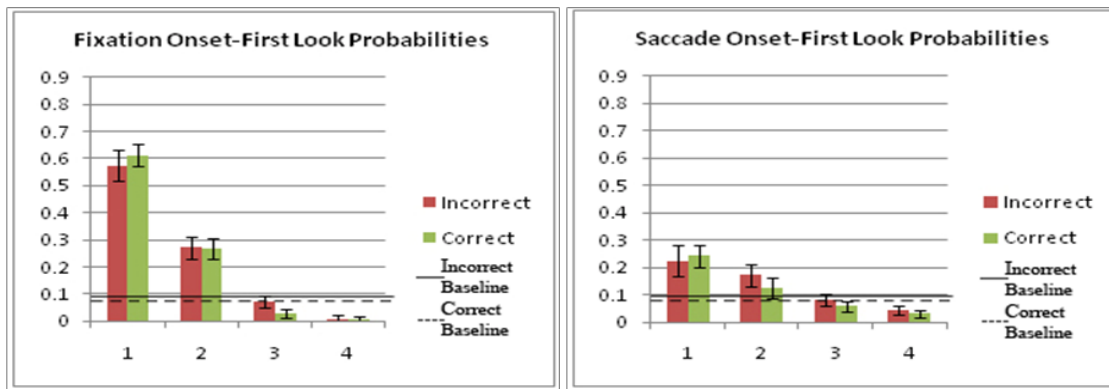


Figure 19: Results of Experiment 2.2. The mean probability that the first look at the critical object occurred at each of the initial four fixations directly after the onset, for objects onset both in correct and incorrect orientations during a fixation (left) or during a saccade (right). Re-fixations are excluded from these first look probabilities. Error bars represent 95% confidence intervals.

Table 4: Average first look probabilities for both fixation and saccade onsets at the four critical ordinal fixation positions.

Ordinal Fixation Position	Fixation	Saccade
1	59.3 %	23.3 %
2	26.9 %	14.9 %
3	4.9 %	6.9 %
4	0.6 %	3.8 %

No main effect of Object Orientation [$F(1, 22) = 1.152, p = .30$] and no interaction with any other factor was found in the probability of first fixation analysis, despite the baseline differences revealed by the comparison of the two conditions in the control group. As will be presented more analytically later, in the control condition where no onsets were present, incorrectly orientated objects received more fixations (3.3% of total time difference, 0.644 fixations) and captured attention for longer (4% of total time difference, 175.772 msec).

ONSET CONDITIONS: Mean fixation probability.

Further analysis was carried out on the mean probability of fixating a critical object which is onset either in its functionally correct or an incorrect orientation, to further explore attentional influences of the action affordance of the onset object, once attention has been directed to the critical object. A 2 (Orientation) \times 4 (Ordinal Fixation Position) \times 2 (Onset Condition) mixed model analysis of variance (ANOVA) was conducted on the mean probability of fixating the critical area after the onset, with Object Orientation (Correct vs. Incorrect) and Ordinal Fixation Position (1-4) as the within-subjects factors and Onset Condition (Fixation vs. Saccade) as the between-subjects factor. The results of this analysis are illustrated in Figure 20.

Analysis revealed a main effect of Onset Condition [$F(1, 22) = 35.523, p < .001$] with onsets happening within a fixation attracting more fixations ($M_F = 56.6\%$) than the onsets within a saccade ($M_S = 28.8\%$). This is consistent with the hypothesis that transient motion signals lead to greater prioritization of scene changes. There was also a main effect of Ordinal Fixation Position [$F(2.1, 46.6) = 11.229, p < .001$, Greenhouse-Geisser correction], with the peak fixation probability at the 2nd ordinal fixation position ($M_2 = 51.9\%$) being significantly higher than the 1st, 3rd and 4th ordinal fixation positions ($M_1 = 41.3\%$, $M_3 = 42.5\%$, $M_4 = 35\%$, all p 's $< .005$)¹³. In short, the main effect of

¹³ The 4th ordinal position's fixation probability was also significantly lower than the 2nd ($p < .001$) and 3rd ($p = .007$) ordinal fixation positions and its difference from the 1st ordinal fixation position also showed a trend for significance ($p = .067$).

Ordinal Fixation Position can be described by a peak of fixation probabilities in the 2nd ordinal fixation position and a gradual decrease after that.

The analysis also revealed a main effect of Object Orientation [$F(1, 22) = 11.609$, $p = .003$], with objects onset in incorrect orientations having a higher mean probability of being fixated ($M_I = 47.3\%$) compared to objects onset in correct orientations ($M_C = 38.1\%$). This main effect might be driven by longer dwell time on incorrectly oriented objects as demonstrated in the baseline analysis and more refixations, as we can conclude by testing this hypothesis in juxtaposition with the first look probability analysis in the previous section. The main effect of Object Orientation was in this case significant, unlike the first look probabilities analysis where there was no Object Orientation main effect. This fact suggests that the significant main effect in the mean fixation probability analysis was probably driven by the increase in refixations in the case of objects onset in an incorrect orientation; the same difference was also evident in the no-onset control condition, where there was a trend for higher mean fixation probabilities at incorrectly oriented objects, as compared to their correct orientations.

Some significant interactions were also revealed. First, the Object Orientation by Ordinal Fixation Position interaction reached significance [$F(3, 66) = 8.769$, $p < .001$]. Planned comparisons revealed that orientation did not affect the two first fixations following the onset, but there were significantly more fixations in the case of objects onset in incorrect orientations in the 3rd ($M_I = 51.4\%$, $M_C = 33.5\%$; $t = 4.357$, $df = 23$, $p < .001$) and 4th ($M_I = 42.7\%$, $M_C = 27.2\%$; $t = 4.481$, $df = 23$, $p < .001$) ordinal fixation positions. Incorrectly oriented objects retained high mean fixation probabilities in the last two ordinal positions of our window of analysis (4 ordinal fixation positions). This

suggests that incorrectly oriented objects retain attention even at later ordinal fixation positions, whereas attention directed to correctly oriented objects is disengaged at earlier ordinal fixation positions.

This effect might be driven again by more refixations to the critical object when it is incorrectly oriented. The fact that Object Orientation did not interact with Ordinal Fixation Position in the first look probability analysis in the previous section verified this hypothesis. The conclusion is drawn due to the fact that mean fixation probabilities remain significantly higher at later ordinal fixation positions (namely the 3rd and 4th) in the case of incorrectly oriented objects as compared to correctly oriented objects (see Figure 20). On the other hand, first look probabilities quickly decrease after the 2nd ordinal fixation position at levels even lower than the baseline since attentional prioritization has forced most of first looks at the first two ordinal fixation positions following the onset (see Figure 20). In this case refixations can be seen as a measure of the amount of time of sustained attention on the critical object.

Second, there was an Ordinal Fixation Position by Onset Condition interaction [$F(3, 66) = 8.202, p < .001$]. Comparison between the two onset conditions showed that mean fixation probabilities (Table 5) were higher for onsets during a fixation in the first 3 ordinal fixation positions ($t_1 = 5.794, t_2 = 7.219, t_3 = 4.333, df = 22, p < .001$), but not for the 4th ordinal fixation position (although there was a trend for significance, $t_4 = 1.952, df = 22, p = .064$). When comparing mean fixation probabilities within each onset condition we discover that in the case of *fixation onset condition*, there was strong prioritization at the first two ordinal fixation positions following the onset which later

markedly decreased, as demonstrated by a number of significant differences between the four critical ordinal fixation positions¹⁴. But the difference between the 1st and the 2nd ordinal fixation positions did not reach significance despite it showed a trend towards significance ($M_{1F} = 59.3\% < M_{2F} = 71.3\%$; $t = -1.952$, $df = 11$, $p = .077$). In the *saccade onset condition* on the other hand, fixation probabilities did not decrease at later ordinal fixation positions and the only significant difference was between the first two ordinal fixation positions ($M_{1S} = 23.3\% < M_{2S} = 32.6\%$; $t = -3.024$, $df = 11$, $p = .012$). The interaction of Ordinal Fixation Position and Onset Condition reveals that attention capture is stronger and happens faster when the onset occurs during fixation and less strong when the onset occurs during a saccade.

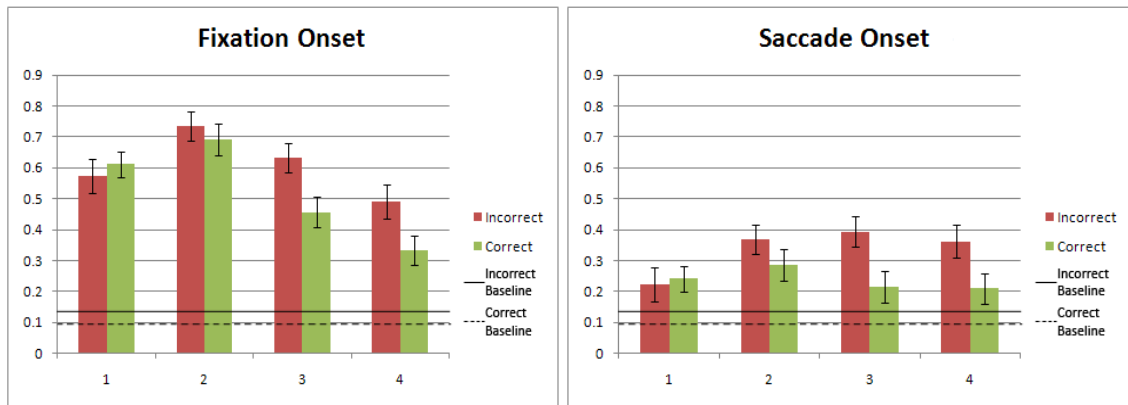


Figure 20: Results of Experiment 2.2. The mean probability that the initial four fixations directly after the onset were localized on the critical object, for objects onset both in correct and incorrect orientations during a fixation (left) or during a saccade (right). Error bars represent 95% confidence intervals.

¹⁴ The 4th ordinal fixation position had significantly lower mean fixation probability ($M_{4F} = 41.3\%$) than the previous three ordinal fixation positions ($M_{1F} = 59.3\%$, $t = 3.594$, $df = 11$, $p = .004$; $M_{2F} = 71.3\%$, $t = 8.083$, $df = 11$, $p < .001$; $M_{3F} = 54.5\%$, $t = 3.726$, $df = 11$, $p = .003$). The 2nd ordinal fixation had significantly lower mean fixation probability than the 3rd ordinal fixations position ($t = 8.404$, $df = 11$, $p < .001$); the difference between the 1st and the 2nd ordinal fixation positions also showed a strong trend but did not reach significance ($t = -1.952$, $df = 11$, $p = .077$).

In the saccade condition, attention remained at the critical object for longer, as indicated by the lack of disengagement in the last two ordinal fixation positions of our time window (Figure 20), in agreement with Brockmole & Henderson's (2005a, 2005b) original experiments. The three way interaction of Object Orientation with Onset Condition and Ordinal Fixation Position was not significant.

Table 5: Mean fixation probabilities for both fixation and saccade onsets at the four critical ordinal fixation positions.

Ordinal Fixation Position	Fixation	Saccade
1	59.3 %	23.3 %
2	71.3 %	32.6 %
3	54.5 %	30.5 %
4	41.3 %	28.7 %

Overall effects of action affordance violations on the deployment of eye-movements.

Even if manipulation of the action affordance of the critical object in the scene is not appropriate or strong enough to affect selection and prioritization of the object, it could still have an effect on post-selection mechanisms related to object identification, modulation of the amount of time that attention should be assigned to the critical object and encoding of the new object in relation to the rest of the scene. Therefore although no main effect of orientation was found in our probability of first look analysis and this factor did not affect prioritization by modulating the Onset Condition by Ordinal Fixation Position interaction, planned comparisons revealed the differences in participants' eye-movements throughout the whole trial in the case of action affordance

violations (as realized here by inappropriate orientations) when compared to the case of objects in their functionally appropriate orientation (see Table 6 for an overview).

When comparing the eye movements of participants in these two different critical object orientation conditions (correct vs. incorrect) in the case of our control group where no object onset was present, significant differences in the amount and the duration of fixations to the critical object were revealed. There was a significant difference in both the total amount of time across all fixations on the critical object ($t = 2.320$, $df = 11$, $p = .041$) as well as the percentage of the duration of the trial spent on the critical object ($t = 2.443$, $df = 11$, $p = .033$), with incorrectly oriented objects receiving in total longer gaze duration than correctly oriented objects. Participants were looking at incorrectly oriented objects for 581.872 msecs on average as compared to 406.1 msecs when looking at correctly oriented objects. In other words, in the incorrect object orientation condition, 13.1% of the trial was spent on looking at the critical object whereas in the correct object orientation condition only 9% of the total duration of the trial was spent on the critical object. Moreover, there was a significant difference between the two conditions in the total number of fixations ($t = 2.186$, $df = 11$, $p = .051$) as well as in the percentage of the total fixations to the critical object in the trial ($t = 2.122$, $df = 11$, $p = .057$), with incorrectly oriented objects attracting on average more fixations (2.217 or 12% of the total number of fixations) than correctly oriented ones (1.572 or 8.7% of the total number of fixations).

Similar results were found in the saccade and fixation onset conditions after the new object appeared in the display. There was a significant difference in both the total amount of time across all fixations to the critical object (Fixation: $t = 3.270$, $df = 11$, $p =$

.007; Saccade: $t = 3.802$, $df = 11$, $p = .003$) as well as the percentage of the duration of the trial spent on the critical object (Fixation: $t = 3.415$, $df = 11$, $p = .006$; Saccade: $t = 3.806$, $df = 11$, $p = .003$), with incorrectly oriented objects receiving in total longer fixation duration than correctly oriented objects (Fixation: 1421.872 VS. 1080.106 msec or 33.1% VS. 25% of the duration of the trial respectively, Saccade: 1238.942 VS. 932.037 msec or 29.2% VS. 22.3% of the duration of the trial respectively). Moreover, there was a significant difference between the two onset conditions in the total number of fixations (Fixation: $t = 3.899$, $df = 11$, $p = .002$; Saccade: $t = 5.064$, $df = 11$, $p < .001$) as well as the percentage of the total fixations to the critical object in the trial (Fixation: $t = 3.647$, $df = 11$, $p = .004$; Saccade: $t = 3.895$, $df = 11$, $p = .002$), with incorrectly oriented objects attracting on average more fixations than correctly oriented ones [Fixation: 5.011 (30.5%) vs. 3.628 (22.6%); Saccade: 3.989 (27.2%) vs. 2.919 (20.5%) respectively].

In addition to these differences analysis of the data from trials of the onset conditions revealed a significant difference between the two object orientation conditions in First Pass Gaze Duration (Fixation: $t = 4.654$, $df = 11$, $p = .001$; Saccade: $t = 2.412$, $df = 11$, $p = .034$) with larger mean first pass gaze duration for incorrectly orientated onset objects as compared to correctly onset objects (Fixation 1069.380 Vs. 774.934 msec; Saccade: 1100.531 - 861.615 msec). First Pass Gaze Duration (the duration of all fixations on the first run) is known to increase when processing semantic inconsistencies (Vo & Henderson, 2009), so it is not surprising that it is significantly bigger in the case where the critical object is onset in an incorrect orientation. Finally there was a trend for a significant difference between the run count (times that the area has been entered and left) in the case of onsets within a saccade ($t = 1.867$, $df = 11$, $p = .089$) but not within a

fixation ($t = 1.398$, $df = 11$, $p = .190$) with slightly greater run count in the case of incorrectly oriented onsets (1.5 vs. 1.3).

As an additional control the same comparisons were also tested in the first half of the trial before the onset, where the critical object was not present. In this case there were of course no significant differences between the two object orientation conditions in the fixations on the critical areas.

Table 6: Differences between correctly and incorrectly oriented objects at each onset condition.

	Fixation				Saccade			
	Incorrect	Correct	Difference	p	Incorrect	Correct	Difference	p
Dwell Time	1421.872	1080.106	341.767	.007	1238.942	932.037	306.905	.003
% Dwell Time	33.1%	25%	8.1%	.006	29.2%	22.3%	6.9%	.003
First Run Dwell Time	1069.380	774.934	294.447	.001	1100.531	861.615	238.917	.034
Fixation Count	5.011	3.628	1.383	.002	3.989	2.919	1.071	.000
% Fixation	30.5%	22.6%	8.1%	.004	27.2%	20.5%	6.7%	.002
Run Count	1.8	1.6	.172	.190	1.5	1.3	.154	.089

In summary (Table 6), after checking some more differences in the fixations between the whole duration of the trials in incorrect and correct orientation onset conditions, we found that there was a superiority of incorrectly as compared to correctly orientated objects in the dwell time (total duration across all fixations) and the percentage of trial time spent on the interest area (dwell time percent), as well as the percentage of fixations (IA fixation percent) and the number of total fixations in the interest area (IA fixation

count). In other words people make more fixations and keep their fixations longer on the critical object when it is onset in an incorrect as compared to a correct orientation.

Exactly the same conclusions were drawn from restricting analyses on the onset period of the experimental condition (the half of the trial after the onset). In addition to the results mentioned above there was a superiority of incorrect orientation in the first pass gaze duration (first run dwell time), a measure which reveals the processing of semantic inconsistencies (Vo & Henderson, 2009) as well as a trend for the times the interest area was entered and left (run count¹⁵, $p=.089$). When restricting analyses to the first half of the trial before an onset (the first 5 seconds of the onset condition), there were of course no significant differences between the two conditions, since the critical object had not yet been presented.

DISCUSSION

The results of our Experiment 2.1 replicated the original Brockmole and Henderson (2005a, 2005b) experiments' findings and provided further evidence for the prioritization of objects suddenly onset in real world scenes. This attentional prioritization was greater for onsets during a fixation but it was also demonstrated at a relatively smaller degree in the case of onsets during a saccade. Our analysis of the speed of prioritization based on first look probabilities failed to provide any evidence of modulation of attentional prioritization based on the action affordance manipulation of

¹⁵ This also was found to be significant when we look only at the last 5 instead of the first 5 seconds in the control condition (where no onset is present) at $p = .02$; Incorrect (.79) > Correct (.62)

the onset object. Object prioritization was similar for both correctly and incorrectly oriented objects onset in a real-world scene. This finding opposes the prediction that motoric activations based on the object's action affordance could pre-attentively affect attentional prioritization. Unlike the semantic consistency experiment (Brockmole & Henderson, 2008) where the semantic consistency of the new object affected its prioritization when onset during a saccade, with new inconsistent objects fixated sooner than new consistent objects, the orientation of the critical object onset affected neither oculomotor capture nor memory guided prioritization.

The lack of a difference between the two onset conditions in memory guided prioritization provides evidence against the hypothesized pre-attentive effects of action affordances. There is the possibility though that automatic prioritization from the visual system in this case is not as sensitive to action affordances as in cases where object recognition is more relevant to the task of the observer. In our task, participants were not instructed to recognise a specific object but we took advantage of the fact that novelty is prioritized by the visual system even without instruction. Even though action affordance manipulations were hypothesized to be similar to semantic consistency manipulations in terms of the violation of scene expectations, it might be the case that semantic effects can be utilized by the visual system sooner than action affordance activations, based on the fast extraction of gist related information about the content of the scene. This effect might be rather based in deviation from relevant schemas, which in the case of semantic violations seems to be detected faster than action affordance violations.

This hypothesis is further supported by our mean fixation probabilities analysis. In our calculation of first look probabilities, we removed the effect of re-fixations that might occur within our time window of four ordinal fixation positions, to provide a clean measure of the speed of oculomotor capture. Given the finding that attentional prioritization is not affected by the orientation of the onset object, we were interested to further explore if attention, once captured, remains on incorrectly oriented objects for longer than correctly oriented ones. As mentioned earlier, the mean fixation probabilities which include refixations could provide such evidence about attention modulation by object orientations, after attention has been drawn to the critical object. Our analysis verified that even though object orientation did not affect the speed of prioritization, it affected the amount of fixations directed to the critical object, with more fixations remaining at the last two ordinal fixation positions of the time window used in the case of incorrectly oriented objects, as compared to correctly oriented ones. Attention seems to linger on incorrectly oriented objects for longer.

Post-selection effects of action affordance manipulations were further explored in our later experiments and our findings will be more analytically discussed in juxtaposition with the findings of those experiments.

EXPERIMENT 2.3

Experiment 2.2 demonstrated that although action affordances, as instantiated by functional positioning manipulations of a correctly or incorrectly oriented object, do not affect the degree or speed of object prioritization pre-attentively, they do affect post-selection mechanisms related to object identification, modulation of the amount of time that attention should be assigned to the critical object and encoding of the new object in relation to the rest of the scene.

Experiment 2.3 aimed to explore whether a functional change in the positioning of a critical object in these real-world scenes can capture attention and cause prioritization of this object, in a way similar to object onsets. The lack of an effect of the action affordance in the prioritization of the onset object provided evidence against the hypothesis that motor representations automatically activated while viewing an object can be used pre-attentively to compare the perceptual input with a stored representation of its normal functioning, and preferentially prioritize incorrectly oriented objects due to the discrepancy from such an action relevant schema.

In this paradigm, where enough viewing time of the critical object before the feature change has been allowed, a sudden orientation change of the critical object introduces a discrepancy of the perceptual input from the on-line representation of the critical object that has been encoded to VWM up to the time point of the change. In this case it is the distance from the newly created memory representation rather than an action relevant schema stored in LTM that could support memory guided prioritization. Moreover, if it

is established that object prioritization can indeed be elicited by orientation changes which affect the action affordance of an object, the direction of this orientation change might also be important.

Feature changes of a critical object in a scene, such as colour changes, have already been demonstrated to cause prioritization (Matsukura, Brockmole & Henderson, 2009). In this experiment we used another type of feature change which is less conspicuous than colour changes in terms of disruption of low level characteristics of the scene, but potentially more behaviourally relevant. Using the same stimuli with the previous eye-tracking experiment we tested the effects of a change in the action affordance of a critical object that was in view all along within a scene. Instead of using an onset, in this case we used the orientation change of a critical object from its correct to an incorrect for its normal functioning orientation, or a reverse change from a non-functional orientation of the critical object to its normal orientation. This way we implemented two possible manipulations of the action affordance of the critical object in the scene, to test their effect on attentional prioritization and the deployment of eye-movements. Either the abolishment of the action affordance, achieved by its change to an inappropriate orientation (Normal Orientation Change) halfway during scene viewing, or the creation

of a useful action affordance, achieved by switching the critical object from a non-functional positioning to its functioning orientation (Reverse Orientation Change¹⁶).

Such an orientation change is more realistic than a colour change in terms of everyday experience, where objects don't suddenly change colour. By saying that it can be potentially behaviourally relevant we mean that action affordance related orientation is related to usage of the object or execution of an action with it, so it is more relevant in the cases where an action is intended during everyday experience. For example, an office worker intending to pick up his coffee cup while working on a PC, might accidentally knock the cup down before the cup is fixated. The pre-planned movement of picking up the supposedly correctly oriented coffee cup would need to be quickly adapted, as soon as the critical object was fixated.

The prioritization paradigm in this case of the object's feature change allows for a greater contribution of scene memory than the paradigm where the object is suddenly onset in the scene, because the critical object had been present in the scene for the time of scene viewing before the event of the change which caused its prioritization. During this time, the presence of the object allowed for memory encoding of its critical characteristics and their relationship with other objects and the rest of the scene (Brockmole & Henderson, 2006; Carlson-Radvansky, 1999; Carlson-Radvansky &

¹⁶ The terminology used to code for the direction of change was arbitrary, so in terms of clearness an object's change from correct to incorrect orientation will be hereafter referred to as "Normal" whereas a change from incorrect to correct orientation will be referred to as "Reverse".

Irwin, 1995; Chun, 2003; Chun & Jiang, 1998; Jiang, Olson & Chun, 2000; Vidal, Gauchou, Tallon-Baudry & O'Regan, 2005). As a result, a final aim of this experiment was to further test the hypothesis of an independent mechanism triggering the allocation of attention on the critical object in the case of saccade changes and explore the role of visual memory in prioritization, by comparing its results with object prioritization in the case of onsets in Experiment 2.2.

The experiment from Matsukura and her colleagues (Matsukura, Brockmole & Henderson, 2009) provides evidence that meaningful feature changes can also lead to prioritization, in addition to objects onset in a scene. Based on the fact that orientation has been reported to be part of the important information bound on an object representation (Van Eccelpoel, Germeys, De Graef & Verfaillie, 2008; Henderson & Hollingworth, 1999b, 2003a; Henderson & Siefert, 1999, 2001) and based on the evidence in favour of object prioritization due to another feature change such as colour (Matsukura, Brockmole & Henderson, 2009), we expect an orientation change that affects the critical object's action affordance to be sufficient to cause prioritization. Based on the evidence about the contribution of memory in memory guided prioritization (Brockmole & Henderson, 2005a, 2005b), orientation changes should be prioritized by the visual system due to the mismatch with the scene representation built during the initial viewing of the scene. On the other hand, our action affordance manipulation introduced minimal low level differences, as compared to colour changes, between the two versions of correct and incorrect object orientations. Therefore, if

prioritization is significantly based on such low-level characteristics, orientation changes might fail to cause attentional prioritization.

The role of visual memory in Experiment 2.2 was demonstrated by the differences in attentional prioritization afforded to critical objects when they were onset during a fixation or saccade (cf. Brockmole & Henderson, 2005a, 2005b). One of our hypotheses to be tested in Experiment 2.2 regarded the direction of the difference in prioritization of objects that violate the functionality schema through an incorrect orientation, compared to the same objects in their correct orientations. According to the suggestion that motor representations are activated in parallel and before object recognition, we hypothesized that such pre-attentive effects on object recognition might affect their prioritization. Experiment 2.2 provided evidence against such pre-attentive effects of action affordances but our control condition analysis provided a hint for the way our action affordance manipulations affected the deployment of eye-movements and consequently attention towards an object after selection.

Comparison of our results with the earlier finding of pre-attentive effects of a similar semantic consistency manipulation in the same paradigm (Brockmole & Henderson, 2008) led us to the conclusion that action affordance effects cannot be used as fast as semantic consistency to pre-attentively compare a perceptual input with relevant action affordance related schemas. Gist related information might affect attentional prioritization much sooner. Still, the effects demonstrated in the control condition of Experiment 2.2 reveal the role of action affordances in the encoding of orientation information regarding the object. Such information could be constantly updated and

compared with a stored template, a schema of the expected positioning of the critical object that will allow for its normal functioning. Based on this fact we could hypothesize that despite the fact that our Experiment 2.2 provided evidence against pre-attentive effects, we might still expect stronger prioritization in the case of normal orientation changes (abolishment of the action affordance), where the incorrectly oriented object after the change has a greater distance from the action affordance relevant schema regarding the object, as compared to reverse orientation changes (creation of an action affordance).

At the same time, the perceptual input could be constantly compared with the online representation of the object, built during viewing of the scene, to allow for detection of unexpected changes. So if what is more important is the mismatch of the perceptual input from the online representation of the object built since the beginning of scene viewing, reverse orientation changes, where an originally incorrectly oriented object is replaced with a correctly oriented one creating a correct action affordance, should lead to greater prioritization. This is because an incorrectly oriented object is expected to attract more fixations (and as an extension more attention) than a correctly oriented one, according to the results of our control condition in the Experiment 2.2. Therefore, an incorrect orientation is hypothesized to make the object better encoded in memory, and prioritization due to a memory-guided process should be easier. As stated before, any such differences should therefore be obvious in memory-guided prioritization during saccade changes and not in oculomotor capture during fixation changes.

METHOD

Participants. Thirty-two volunteers (mostly students, recruited from Edinburgh University's career services website) participated in the research for an honorarium of £4 (16 participants in each experimental group. Normal orientation change: 11 female, 5 male, mean age = 20.94 years. Reverse orientation change: 12 female, 4 male, mean age = 22.25 years). All the participants had normal or corrected to normal vision and were naïve to the experimental hypothesis. Half the participants were allocated to the Normal orientation change condition and the other half were allocated to the Reverse orientation change experimental condition. Data from the control condition of the previous onset experiment were used as a comparison baseline.

Stimuli and Apparatus. Stimuli consisted of the same 60 colour photographs of 30 everyday real world scenes used in Experiments 2.1 (action consistency stimulus set) and 2.2 (see Figure 16 for an example). For each scene an object was selected whose orientation is critical for its normal use (again same with the previous experiment, see Table 3). Each scene was photographed with its corresponding critical object in its correct (appropriate for use, Figure 16, panels A and D) orientation and in an incorrect orientation (e.g. upside down, Figure 16, panels B and C). The incorrect orientation abolished the potential for using or acting upon the critical object. Photographs were edited where necessary to eliminate minor differences in shadowing or object placement that may have occurred between the two shots.

The apparatus used and its configuration were identical to Experiment 2.2.

Design and Procedure. Object prioritization among three object orientation change conditions (saccade, fixation or no change) was compared. The design replicated the format of the previous experiment, with the only difference that instead of the onset of a critical object either in the correct or an incorrect orientation, there was an orientation change of a critical object that was present in the scene all along. As described earlier, two different Experimental Groups were tested, with the critical object changing from the correct to an incorrect orientation in the first group and from an incorrect to the correct orientation for the second group.

The aim of this experiment was to test if there can be prioritization of the critical object when no onset occurs, but only an abolishment of the action affordance of the object in the scene achieved by change to an inappropriate orientation (Figure 21 top), or the creation of a useful action affordance (functional positioning) by change to the correct orientation (Figure 21 bottom). At the same time, in case such a prioritization exists, a second aim of this experiment was to compare the effects of the direction of the orientation change on it.

The participants took part in a computer-based mock memorization task while their eye-movements were recorded. Participants were instructed to study all 30 scenes for 10 seconds each for a subsequent memory test. Their eye movements were recorded during scene viewing. No memory test was actually administered as the critical manipulations occurred while observers were studying the scenes.



Figure 21: An example scene for the photographs used in this study before (left) and after (right) the orientation change. In the top the critical object changes to an incorrect whereas in the bottom to a correct orientation. The yellow square marking the critical object is for reference only here and was not part of the experimental stimuli.

Participants had already been assigned in one of the two Experimental Groups (Normal vs. Reverse) before testing. In the object orientation change conditions, the critical object's orientation change occurred either during a saccade (in half the trials) or during a fixation (in the other half). In the control condition, the critical object was present from the beginning of the trial. For the Normal Orientation Change Experimental Group, both in the saccade and the fixation object orientation change conditions, all the trials started with the photograph with the critical object in the correct orientation and it was later replaced with the one with the object in an incorrect condition. For the Reverse Orientation Change Experimental Group, all the trials started with the photograph with

the critical object in an incorrect orientation, which was later replaced with the one with the object in the correct condition. In the control condition, the same photograph with the critical object in the correct or incorrect orientation remained on view for the whole duration of the trial (see control condition in Experiment 2.2).

The experimental session began by calibrating the eye-tracker for every participant. Calibration was then monitored throughout the experiment and re-adjusted if necessary. Each trial started with the participant looking at a dot in the centre of the screen. A button press served to begin a drift correction procedure and to present the scene image. After the button press a scene was displayed for approximately 10 seconds. The orientation change of the critical object occurred either during a saccade (randomly assigned in half the images) or during a fixation (in the other half). In the saccade condition this change in the display image happened during the first saccade executed after 5 seconds had elapsed from the beginning of the trial so that the eyes were still moving during the change. For the fixation condition the change happened 100 msecs after the onset of the first saccade executed after 5 seconds of scene viewing. This allowed enough time for this saccade to terminate, but not enough for another one to commence, thus allowing the change to happen when the eyes were still.

RESULTS

The same analyses as in the previous onset experiment were employed. First, the probability of the critical object being fixated after its orientation change was compared with the probability it was fixated when the object was in view all along, to verify that

this probability surpasses chance (baseline probabilities were taken from the onset experiment). Also, paralleling previous experiments, both mean fixation probabilities and the speed of prioritization (first look probabilities) were considered to see whether prioritization based on oculomotor capture would be evident sooner than that based on memory guided prioritisation.

The regions of interest and coding of fixations were computed in the same way described in Experiment 2.2. Because we were interested in characterizing the initial prioritization of a new object soon after its appearance in a scene, analyses were confined in the first 4 fixations after the orientation change, as in our previous onset experiment. The only difference was that our data were further filtered to reduce noise. First, two of our stimuli which received significantly lower ratings compared to the rest of the stimulus set at a separate experiment (Experiment 2.1) where independent observers were asked to rate the effectiveness of the action affordance manipulation, were excluded from the current analysis¹⁷.

Moreover, trials were filtered based on whether the critical object had been fixated before the change. Trials where the critical objects were not fixated at the time period before the change were also excluded from analysis. This led us to drop from this

¹⁷ The same objects were included in the analysis of Experiment 2.2 and they did not affect its results. Even when they were included in the current experiment they did not significantly affect the results. In this experiment though, where the fixation pattern of the critical object before the orientation change was important for memory guided prioritization, we wanted our action affordance stimulus set to be as concise as possible, even if it meant an over-conservative correction such as dropping these two items.

analysis 33.4% of the trials in the Normal Orientation Change Experimental Group and 15.9% of the trials in the Reverse Orientation Change Experimental Group. Because the aim of the current experiment was to further explore the role of memory for object orientation in attentional prioritization, based on the indications of the control condition analysis and the mean fixation probability analysis of experiment 2.2, we needed to verify that in the trials analyzed participants had directed their attention to the critical object before the change. It is the mismatch of the object orientation before and after the change that might be guiding memory guided-prioritization according to our hypothesis, so cases where the critical object was not fixated before the change would add noise to our dataset. For all analyses reported below, an alpha level of .05 was adopted as criterion for statistical significance and where assumptions of sphericity were violated, Greenhouse-Geisser corrections were used.

The same analyses were carried out for both Experimental Groups (Normal vs. Reverse). These analyses will be presented comparatively below for both Normal and Reverse Orientation Change Experimental Groups, along with further analyses comparing prioritization between the two.

NORMAL ORIENTATION CHANGE EXPERIMENTAL GROUP: Probability of first look.

First look probability analysis was again used as a measure of the speed of object prioritization, as in the onset experiment (Experiment 2.2). A 2 (Object Change Condition) \times 2 (Ordinal Fixation Position) within-subjects analysis of variance (ANOVA) was conducted on the probability of first looking at the critical area. The

within subjects factors were Object Change Condition (Fixation vs. Saccade) and Ordinal Fixation Position (1-4). It is reminded that in this analysis fixation probabilities were filtered so that they do not include refixations but only show the probability that the critical object was fixated for the first time at each of the 4 ordinal fixation positions of interest. The results of this analysis are illustrated in Figure 22 (right).

Analysis revealed a significant main effect of Object Change Condition [$F(1, 15) = 48.141, p < .001$], with changes happening within a saccade having lower probability of being looked at for the first time ($M_S = 12.8\%$) compared to changes within a fixation ($M_F = 23.8\%$). There was also a main effect of Ordinal Fixation Position [$F(1.78, 26.64) = 25.116, p < .001$, Greenhouse-Geisser correction] with first look probabilities in the first two ordinal fixation positions after the change significantly higher from the ones following them. This indicates that there is fast prioritization of the critical object during the first two fixations immediately following the change. More specifically, the probability of first look in the 1st ordinal fixation position was significantly higher than the 2nd, 3rd and 4th ordinal fixation positions ($M_1 = 39.2\%$, $M_2 = 23.1\%$, $M_3 = 6.9\%$, $M_4 = 4\%$, $p < .028$). The probability of first look at the 2nd ordinal fixation position was also significantly higher than the 3rd ($p = .006$) and 4th ($p = .001$) ordinal fixation positions.

More importantly, there was also a significant interaction of Object Change Condition and Ordinal Fixation Position [$F(3, 45) = 20.074, p < .001$]. In the case of

changes within a saccade planned comparisons revealed that the only¹⁸ significant difference in probabilities of first look was between the 1st ($M_{1S} = 19.2\%$) and 4th ($M_{4S} = 8.1\%$) ordinal fixation positions ($t = 2.263$, $df = 15$, $p = .039$). In the case of *changes within a fixation* on the other hand the first two ordinal fixation positions had significantly higher probabilities of first look from the ordinal positions following them (all p 's $< .001$)¹⁹.

For changes happening within a fixation, probabilities of first looking at the critical object after the change were significantly higher at almost every ordinal fixation position compared with the ones that follow, gradually dropping at later ordinal fixation positions. For changes happening within a saccade though, prioritization is happening slower and is equally spread at the first two fixations following the change, dropping at the third and fourth ordinal fixation positions.

NORMAL ORIENTATION CHANGE EXPERIMENTAL GROUP: Mean Fixation Probability.

A 2 (Object Change Condition) \times 2 (Ordinal Fixation Position) within-subjects analysis of variance (ANOVA) was conducted on the probability of fixating the critical

¹⁸ There were some more comparisons that showed a trend but did not reach significance [$M_1 > M_3$ ($p = .073$); $M_2 > M_4$ ($p = .095$)]

¹⁹ The probability of first looking at the critical object in the 1st ordinal fixation position ($M_{1F} = 59.1\%$) was significantly higher than the 2nd ($M_{2F} = 28.4\%$, $t = 4.508$, $df = 15$, $p < .001$), 3rd ($M_{3F} = 5.6\%$, $t = 13.594$, $df = 15$, $p < .001$) and 4th ($M_{4F} = 2\%$, $p < .001$, $t = 17.086$, $df = 15$, $p < .001$) ordinal fixation positions. The same probability in the 2nd ordinal fixation position was also significantly higher than the 3rd ($t = 4.338$, $df = 15$, $p = .001$), whose difference from the 4th ordinal fixation position also showed a trend for significance ($t = 1.773$, $df = 15$, $p = .097$).

area. Object Change Condition (Fixation vs. Saccade) and Ordinal Fixation Position (1-4) were the within-subjects factors. The results of this analysis are illustrated in Figure 22 (left).

Analysis revealed a main effect of Object Change Condition [$F(1, 15) = 42.389, p < .001$], with changes happening within a saccade having lower probability of being fixated ($M_S = 29.1\%$) compared to changes within a fixation ($M_F = 61\%$). This is again consistent with the hypothesis that transient motion signals lead to greater prioritization of scene changes. There was also a main effect of Ordinal Fixation Position [$F(3, 45) = 6.562, p = .001$], with the peak fixation probability at the 2nd ordinal fixation position. The probability of fixating at the critical object at the second ordinal fixation position after the change ($M_2 = 56.3\%$) was significantly higher than the 1st, 3rd and 4th ordinal fixation positions ($M_1 = 39.2\%, M_3 = 46.7\%, M_4 = 38\%, p < .05$). Moreover, the fixation probability in the 3rd ordinal fixation position was significantly higher than the 4th ($p = .03$).

Finally there was also a trend towards an interaction of Object Change Condition and Ordinal Fixation Position, although it did not reach significance [$F(1.69, 25.33) = 2.759, p = .090$, Greenhouse-Geisser correction]. Fixation probabilities were dropping faster in the case of changes within a fixation as compared with changes within a saccade, where fixation probabilities remained equally high after the second ordinal position and throughout our time window of the 4 ordinal fixation positions following the change. In the case of *changes within a saccade* planned comparisons indicated significant differences in fixation probabilities only between the first two ordinal fixation positions ($M_{1S} = 19.2\% < M_{2S} = 36.2\%, t = -2.823, df = 15, p = .013$). In the

case of *changes within a fixation* after the peak of the 2nd ordinal fixation position there was also a significant drop in fixation probabilities at each ordinal fixation position as compared to the previous ones (all p 's < .024)²⁰.

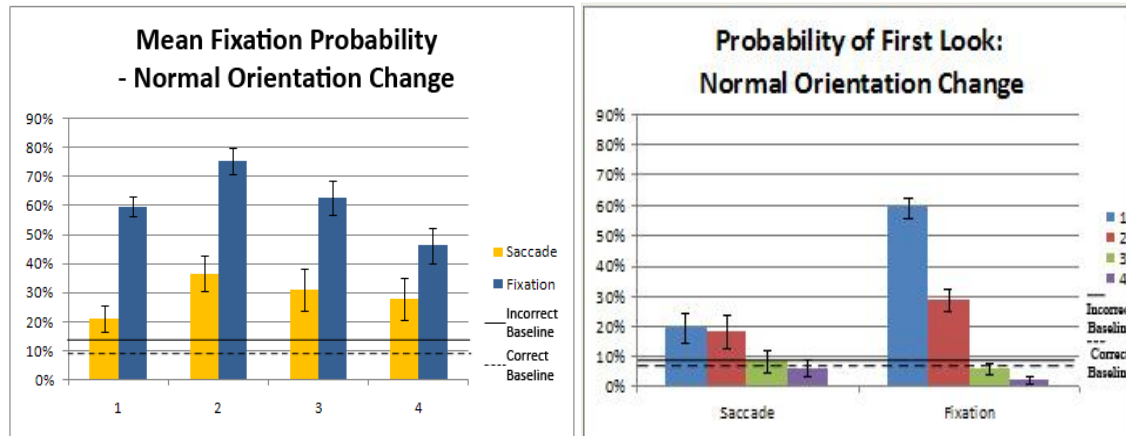


Figure 22: Results of Experiment 2.3 for the Normal Orientation Change Experimental Group. Left: The mean probability that the initial four fixations directly after the critical object's direction change from a correct to an incorrect orientation were localized on it, for changes occurring both during a fixation and during a saccade. Right: The mean probability that the first look at the critical object occurred at each of the initial four fixations directly after the direction change, for changes occurring both during a fixation and during a saccade. Re-fixations are excluded from these first look probabilities. Error bars represent 95% confidence intervals.

REVERSE ORIENTATION CHANGE EXPERIMENTAL GROUP: Probability of first look.

A 2 (Object Change Condition) \times 2 (Ordinal Fixation Position) within-subjects analysis of variance (ANOVA) was conducted on the probability of first looking at the

²⁰ The 2nd ordinal fixation position after the change ($M_{2F} = 76.5\%$) attracted on average significantly more fixations than the 1st ($M_{1F} = 59.1\%$, $t = -3.229$, $df = 15$, $p = .006$), 3rd ($M_{3F} = 61.8\%$, $t = 2.517$, $df = 15$, $p = .024$) and 4th ($M_{4F} = 46.8\%$, $t = 4.664$, $df = 15$, $p < .001$) ordinal fixation positions. The mean fixation probability of the 3rd ordinal fixation position was also significantly higher from the 4th ($t = 3.272$, $df = 15$, $p = .005$).

critical area. Object Change Condition (Fixation vs. Saccade) and Ordinal Fixation Position (1-4) were the within-subjects factors. The results of this analysis are illustrated in Figure 23 (right).

Our analysis revealed a main effect of Object Change Condition [$F(1, 15) = 19.170$, $p = .001$], with changes happening within a saccade having lower probability of being looked at for the first time ($M_S = 15\%$) compared to changes happening within a fixation ($M_F = 22\%$). There was also a main effect of Ordinal Fixation Position [$F(1.42, 21.34) = 60.942$, $p < .001$, Greenhouse-Geisser correction], with the 1st and 2nd ordinal fixation positions' first look probabilities being significantly higher than the ones that followed, but also being significantly different for one another. More specifically, the probability of first look in the 1st ordinal fixation position ($M_1 = 51.4\%$) was significantly higher than the 2nd ($M_2 = 14.2\%$), 3rd ($M_3 = 4.8\%$) and 4th ($M_4 = 3.6\%$) ordinal fixation positions ($p < .001$). Also the probability of first look in the 2nd ordinal position was significantly higher from the 3rd and 4th ordinal fixation positions ($p < .001$).

Finally the Object Change Condition by Ordinal Fixation Position interaction was also significant [$F(1.68, 25.18) = 13.082$, $p < .001$, Greenhouse-Geisser correction]. In the case of *changes within a saccade*, planned comparisons revealed significant differences in first look probabilities, with the probability significantly higher in the 1st

ordinal fixation position as compared to the later ones (all p 's < .004)²¹. For *changes within a fixation* both the first two ordinal fixation positions' first look probabilities were significantly higher from the ordinal fixation positions following them (all p 's < .001)²².

For changes happening during a saccade, first look probabilities were again higher in the first few fixations immediately following the change. In the case of reverse orientation direction of change though, object prioritization happens faster than in the case of normal orientation change (as early as from the 1st ordinal fixation position immediately following the change) and more readily resembles the oculomotor capture in the case of the change happening within a fixation.

REVERSE ORIENTATION CHANGE EXPERIMENTAL GROUP: Mean Fixation Probability.

A 2 (Object Change Condition) \times 2 (Ordinal Fixation Position) within-subjects analysis of variance (ANOVA) was conducted on the mean probability of fixating the critical area with Object Change Condition (Fixation vs. Saccade) and Ordinal Fixation Position (1-4) as the factors. The results of this analysis are illustrated in Figure 23 (left).

²¹ More analytically first look probability was significantly higher in the 1st ordinal fixation position ($M_{1S} = 37.7\%$) as compared to the 2nd ($M_{2S} = 11.4\%$, $t = 3.418$, $df = 15$, $p = .004$), 3rd ($M_{3S} = 5.5\%$, $t = 5.451$, $df = 15$, $p < .001$) and 4th ($M_{4S} = 5.2\%$, $t = 5.916$, $df = 15$, $p < .001$) ordinal fixation positions.

²² The probability of first look was significantly higher in the 1st ordinal fixation position ($M_{1F} = 65.1\%$) compared to the 2nd ($M_{2F} = 16.9\%$, $t = 7.562$, $df = 15$, $p < .001$), 3rd ($M_{3F} = 4.1\%$, $t = 10.981$, $df = 15$, $p < .001$) and 4th ($M_{4F} = 1.9\%$, $t = 12.735$, $df = 15$, $p < .001$) ordinal fixation positions. Similarly the probability of first look in the 2nd ordinal fixation position was significantly higher than the 3rd ($t = 4.442$, $df = 15$, $p < .001$) and 4th ($t = 5.134$, $df = 15$, $p < .001$) ordinal fixation positions.

Analysis of mean fixation probabilities also revealed a main effect of Object Change Condition [$F(1, 15) = 39.234, p < .001$], with changes happening within a saccade having lower probability of being fixated ($M_S = 27.7\%$) compared to changes within a fixation ($M_F = 49.2\%$). This is again consistent with the hypothesis that transient motion signals lead to greater prioritization of scene changes. There was also a main effect of Ordinal Fixation Position [$F(3, 45) = 17.584, p < .001$], with the 1st and 2nd ordinal positions' mean fixation probabilities being significantly higher than the ones that followed. In comparison to the normal orientation change direction experiment though, the peak fixation probability in this case was at the 1st ordinal fixation position and demonstrated a gradual drop thereafter. More specifically, 1st ordinal fixation position's mean fixation probability ($M_1 = 51.4\%$) was significantly higher than the 2nd ($M_2 = 42.9\%, p = .032$), 3rd ($M_3 = 30.8\%, p < .001$) and 4th ($M_4 = 28.5\%, p < .001$) ordinal fixation positions. Similarly mean fixation probability was significantly higher in the 2nd as compared to the 3rd ($p = .008$) and 4th ($p = .002$) ordinal fixation positions.

Finally, the Object Change Condition by Ordinal Fixation Position interaction was also significant [$F(3, 45) = 4.838, p = .005$]. In the case of *changes within a saccade* planned comparisons revealed several significant differences in fixation probabilities which were gradually dropping at later ordinal positions, as compared to the previous

ones (all p 's < .028)²³, although there was a slight increase in the 4th ordinal position as compared to the 3rd ($t = -2.306$, $df = 15$, $p = .036$). In *changes within a fixation* the first two ordinal positions' probabilities were significantly higher than the last two (all p 's < .033)²⁴ and the difference between the 3rd and 4th ordinal positions was also significant.

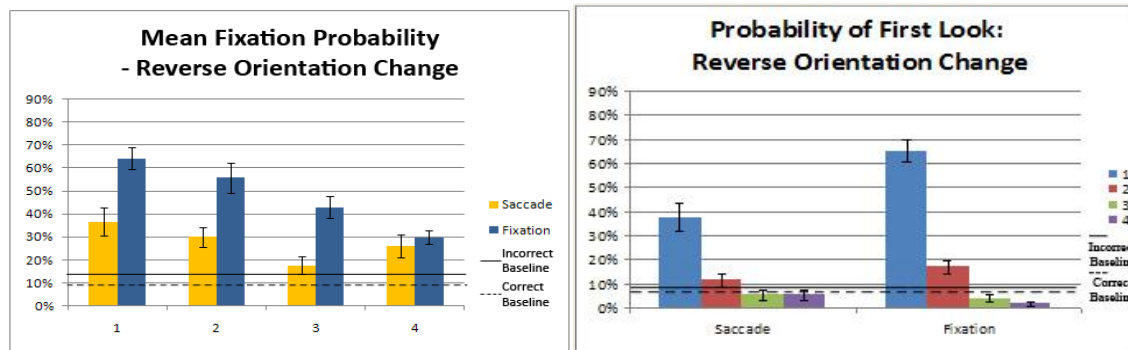


Figure 23: Results of Experiment 2.3 for the Reverse Orientation Change Experimental Group. Left: The mean probability that the initial four fixations directly after the critical object's direction change from an incorrect to a correct orientation were localized on it, for changes occurring both during a fixation and during a saccade. Right: The mean probability that the first look at the critical object occurred at each of the initial four fixations directly after the direction change, for changes occurring both during a fixation and during a saccade. Re-fixations are excluded from these first look probabilities. Error bars represent 95% confidence intervals.

²³ More analytically the probability of fixation in the 1st ordinal fixation position ($M_{1S} = 37.7\%$) was significantly higher than the 3rd ($M_{3S} = 18\%$, $t = 3.85$, $df = 15$, $p = .002$) and 4th ($M_{4S} = 25.8\%$, $t = 2.605$, $df = 15$, $p = .020$) ordinal fixation positions. Also fixation probability is higher in the 2nd ordinal fixation position ($M_{2S} = 29.2\%$) as compared to the 3rd ($t = 2.43$, $df = 15$, $p = .028$), which is also significantly lower than the 4th ordinal fixation position ($t = -2.306$, $df = 15$, $p = .036$).

²⁴ Specifically fixation probability in the 1st ordinal fixation position ($M_{1F} = 65.1\%$) is significantly higher than the 3rd ($M_{3F} = 43.6\%$, $t = 4.342$, $df = 15$, $p = .001$) and 4th ($M_{4F} = 31.3\%$, $t = 7.6$, $df = 15$, $p < .001$) ordinal fixation positions. Also fixation probability in the 2nd ordinal fixation position ($M_{2F} = 56.7\%$) is significantly larger than the 3rd ($t = 2.348$, $df = 15$, $p = .033$) and 4th ($t = 3.865$, $df = 15$, $p = .002$) ordinal fixation positions. Finally mean fixation probability is higher in the 3rd ordinal fixation position as compared to the 4th ($t = 3.115$, $df = 15$, $p = .007$).

COMPARISON OF THE RESULTS OF THE TWO EXPERIMENTAL GROUPS

Probability of First Look. To compare the probability of first look (and the speed of prioritization in extension) to a critical object whose orientation is changed either from the correct to an incorrect orientation (Normal Orientation Change) or from an incorrect to the correct orientation (Reverse Orientation Change) two 2-way within subject ANOVAs were employed. Excluding refixations and considering first fixation probabilities to the critical object after the change, a significant main effect of both Object Change Condition [Saccade vs. Fixation. *Normal*: $F(1, 15) = 48.141, p < .001$; *Reverse*: $F(1, 15) = 19.170, p = .001$] and Ordinal Fixation Position [1-4. *Normal*: $F(1.78, 26.64) = 25.116, p < .001$; *Reverse*: $F(1.42, 21.34) = 60.942, p < .001$] was found. In both Experimental Groups the probability of first look is bigger for changes within a fixation, where transient motion adds to attentional prioritization, rather than for changes within a saccade. Also attentional prioritization happens in the first two ordinal positions, gradually decreasing in the last two.

However comparison of the interaction of Object Change Condition and Ordinal Fixation Position between the two Experimental Groups is revealing (Figure 24). Even though the interaction is significant for both [*Normal*: $F(3, 45) = 20.074, p < .001$; *Reverse*: $F(1.68, 25.18) = 13.082, p < .001$], planned comparisons reveal the differences in prioritization among fixation and saccade changes within each Experimental Group. *When the change happens within a fixation*, the pattern of first look probabilities in the 4 critical ordinal fixation positions is almost identical in both experiments, with most first

looks in the 1st ordinal fixation position after the change and gradual decrease after it.

When the change happens during a saccade, the probability of first look in the 1st ordinal fixation position is significantly higher than the rest ordinal fixation positions in Reverse Orientation Changes. In Normal Orientation Changes, the difference between the first two ordinal fixation positions from the last two positions indicates a trend for significance, but the only significant difference appears to be between the 1st and last (4th) ordinal fixation positions.

The graph describing the Object Change Condition by Ordinal Fixation Position interaction for saccade changes in the two Experimental Groups (Figure 24 left) reveals that prioritization happens faster in the case of *Reverse Orientation Changes* with the probability much higher in the 1st ordinal fixation position as compared to the 2nd ordinal fixation position. In *Normal Orientation Changes*, attention capture is less big and equally distributed among the two first ordinal fixation positions, whose first fixation probabilities do not differ from one another. This comparison is critical for the experimental hypothesis, revealing that memory guided prioritization happens faster in the Reverse Orientation Change of the critical affordance of the object, as indicated by the significant difference between the 1st and 2nd ordinal fixation positions, whereas these two positions do not differ significantly in the case of Normal Orientation Changes.

In short, object prioritization during a saccade change happens faster in the case of Reverse Orientation Changes (1st Experimental Group) and more readily resembles attentional prioritization triggered by the transient motion signals accompanying an

orientation change during a fixation. Prioritization during a saccade of a Normal Orientation Change (2nd Experimental Group) is significantly weaker from both a reverse orientation saccade change, as well as from prioritization due to changes during a fixation.

Mean Fixation Probability. To compare the mean probability of fixation (and subsequently the modulation of attention after the object's prioritization) to a critical object whose orientation is changed either from the correct to an incorrect (Normal Orientation Change) or from an incorrect to the correct orientation (Reverse Orientation Change), two 2-way repeated measures ANOVAs were employed (Figure 24). Considering mean fixation probabilities to the critical object after the change, a significant effect of Object Change Condition [Saccade vs. Fixation. *Normal*: $F(1, 15) = 42.389$, $p < .001$; *Reverse*: $F(1, 15) = 39.234$, $p < .001$] and Ordinal Fixation Position [1-4. *Normal*: $F(3, 45) = 6.562$, $p = .001$; *Reverse*: $F(3, 45) = 17.584$, $p < .001$] were found for both experiments. A significant effect of the interaction between them (Object Change Condition & Ordinal Fixation Position) was also found in the case of Reverse Orientation Change [$F(3, 45) = 4.838$, $p = .005$]. The same interaction showed a trend but did not reach significance in the case of Normal Orientation Change [$F(1.69, 25.33) = 2.759$, $p = .090$, Greenhouse-Geisser correction²⁵].

²⁵ The uncorrected p value would be marginally significant at $p = .051$.

The main effect of Object Change Condition in both Experimental Groups is in line with the superiority of the transient signal in attracting attention, leading to more fixations (both first fixations and refixations) to the critical object in the fixation rather than the saccade change condition. Although the main effect of Ordinal Fixation Position was significant for both Experimental Groups, the distribution of mean fixation probabilities across the 4 ordinal fixation positions of interest was different between the Normal and Reverse Orientation Changes.

In the case of a *Normal Orientation Change*, the peak of mean fixation probabilities is the 2nd ordinal fixation position and the probabilities gradually decrease after that, the distribution being more close to the one we found in the onset paradigm. In the case of *Reverse Orientation Change* there is a peak of mean fixation probability directly after the change (1st ordinal fixation position) and a decrease after that. It seems that the visual system does not notice the change immediately in the Normal Orientation Change, but there is a delay of one more fixation. This might be based on the critical object being less prominent for encoding in memory when it starts with a correct orientation as compared to an incorrect (see also the baseline differences before the change from the control condition in Experiment 2.2).

Finally, the Object Change Condition and Ordinal Fixation Position interaction was significant only in the case of Reverse Orientation Change. The interaction in this Experimental Group was caused by a slight increase in fixation probability of the last (4th) ordinal fixation position as compared to the 3rd ordinal fixation position in the case of changes within a saccade, whereas in the case of changes within a fixation there was a

slight further drop in the same last ordinal fixation position as compared to the previous one.

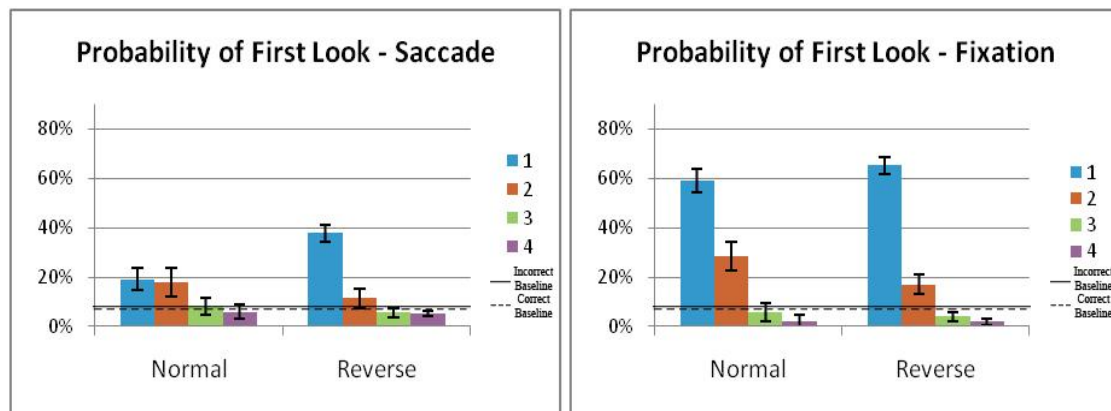


Figure 24: The probability of first look to the critical area at each ordinal fixation position immediately following the change, for both Normal and Reverse Orientation Changes. Results from both analyses are presented for the trials in which orientation change happened during a saccade (left) or a fixation (right). The baseline probability of first look was 8.6% for the incorrect orientation and 6.7% for the correct orientation (their difference is not statistically significant). Error bars represent 95% confidence intervals.

DIRECT COMPARISON BETWEEN THE TWO OBJECT ORIENTATION CONDITIONS.

The difference in object prioritization of an orientation change happening either from a correct to an incorrect direction (Normal) or the other way round (Reverse) was indirectly assessed by comparing among these two Experimental Groups, which only differed in the direction of the orientation change.

By comparing between the two Experimental Groups we wanted to see whether the direction of object orientation change would affect its prioritization. The idea behind this comparison is that in the case that the image displayed starts with an object in an incorrect orientation, it would attract more fixations compared to the case where the image would start with the same object in the correct orientation. This would lead to

better memorisation of the critical object. Therefore during the memory guided saccade change the direction of the object change from an incorrect to a correct orientation should lead to greater attention capture and faster object prioritization, compared to a direction of change from a correct to an incorrect orientation. In the case of the change happening during a fixation, where no effect of memory is expected, the oculomotor capture contingent object prioritization should not be affected by the direction of its orientation change.

Analysis. Our hypothesis was further examined by directly comparing the critical object prioritization caused by the two orientation change directions happening within a saccade with a single statistical analysis. As argued earlier, the probability that the critical object was fixated for the first time at each ordinal fixation position (probability of first look) was used as a measure of the prioritization speed. The trials where the change occurred within a saccade from both Experimental Groups were pooled together and were further analyzed with a 2 (Orientation Change Direction) \times 4 (Ordinal Fixation Position) mixed - factor analysis of variance (ANOVA). A within- and a between-subjects factor were orthogonally crossed. The between subjects factor was Orientation Change Direction (Normal vs. Reverse) and the within subjects factor was Ordinal Fixation Position (1 to 4).

Results. The results of the analysis for the saccade trials from the two Experimental Groups are illustrated in Figure 24 (left). Analysis revealed a significant main effect of Ordinal Fixation Position [$F(2.20, 65.97) = 12.554, p < .001$ (Greenhouse-Geisser correction)], with the probability of first look significantly higher in the 1st ordinal

fixation position ($M_{1S} = 28.5\%$) as compared to the 2nd ($M_{2S} = 14.7\%$, $p = .021$), 3rd and 4th ($M_{3S} = 6.8\%$, $M_{4S} = 5.6\%$, $p < .001$) ordinal fixation positions; also the 2nd ordinal fixation position's first look probability was significantly higher than the 4th ($p = .032$) and showed a trend towards significance when compared to the 3rd ($p = .062$) ordinal fixation position.

More critically the Ordinal Fixation Position by Orientation Change Direction interaction was also significant [$F(3, 90) = 3.525$, $p = .018$]. Planned comparisons revealed a significant difference between the two Experimental Groups only for the 1st ordinal fixation position ($t = 2.464$, $df = 30$, $p = .02$), with the probability of first look being significantly higher in the case of Reverse ($M_{1R} = 37.7\%$) as compared to Normal ($M_{1N} = 19.2\%$) Orientation Changes. The differences between later ordinal fixation positions among the two Experimental Groups were not significant.

As a control to our hypothesis the same analysis was also done on the trials from the fixation change condition of the two Experimental Groups (Figure 24, right). Analysis revealed a significant main effect of Ordinal Fixation Position [$F(1.75, 52.38) = 151.249$, $p < .001$, Greenhouse-Geisser correction] with probabilities of first look in the first two ordinal fixation positions being significantly different from the last two, as well as from one another (all p 's $< .001$)²⁶. The Ordinal Fixation Position by Orientation

²⁶ The probability of first look in the 1st ordinal fixation position ($M_1 = 62.1\%$) was significantly higher than the 2nd ($M_2 = 22.6\%$), 3rd ($M_3 = 4.9\%$) and 4th ($M_4 = 2\%$) ordinal fixation positions ($p < .001$). Also

Change Direction interaction did not reach significance, despite a trend²⁷ towards this direction [$F(3, 90) = 2.569, p = .059$]. Post-hoc comparisons reveal that this interaction is driven by a small difference in first look probabilities of the 2nd ordinal fixation position between the two Experimental Groups (M_{IN} vs. M_{IR} : $t = -2.408, df = 30, p = .022$).

Covariate Analysis. As an additional control, the number of fixations and the amount of time spent on the critical object before the change was taken into account, in a covariate analysis to further explore the difference between the two Experimental Groups. The reported difference might be a result of the difference in the distribution and duration of the eye-movements before the functionality change, based on the correct or incorrect orientation of the critical object. As demonstrated in our control condition, as well as the experimental conditions after the onset in Experiment 2.2, incorrectly oriented objects attract more and longer fixations than correctly oriented objects. Therefore the difference in object prioritization between the two Experimental Groups might be accounted for by the difference in fixation time before the orientation change. In that case, including the duration of the fixations on the critical object before the change as a covariate would result in the critical interaction of Ordinal Fixation Position

the probability of first look in the 2nd ordinal fixation position was significantly higher than the 3rd and 4th ordinal fixation positions ($p < .001$).

²⁷ Posthoc comparisons reveal that this interaction is driven by a small difference in first look probabilities of the 2nd ordinal fixation position between the two experiments (M_{IN} vs. M_{IR} : $t = -2.408, df = 30, p = .022$).

and Orientation Change Direction in the case of changes during a saccade to be no longer significant.

On the other hand, it might be the case that the difference in object prioritization between the two Experimental Groups is not simply due to the differences in the total fixation duration before the orientation change. Other factors, such as the contribution of motor areas of the brain or differences in the nature of the memory representation of action affordance violations as compared to correct functional positioning could be contributing to the difference of the object prioritization between the two Experimental Groups. In that case, even after including the total fixation duration before the change as a covariate, the critical interaction between Ordinal Fixation Position and Orientation Change Direction should remain unaffected.

The total fixation dwell time on the critical object before the change (Pre-change Fixation Dwell Time) was added as a covariate in the 2 (Orientation Change Direction) \times 4 (Ordinal Fixation Position) mixed - factor analysis of variance (ANOVA) presented above. This analysis verified our hypothesis that after controlling for the effects of the pre-change total fixation time, the interaction between Ordinal Fixation Position and Orientation Change Direction was no longer significant [$F(3, 87) = .052, p = .98$]. Pre-change Fixation Dwell Time on its own was a significant predictor of object prioritization [$F(1, 29) = 8.388, p = .007$]. Finally Pre-change Fixation Dwell Time interacted with the within-subjects factor of Ordinal Fixation Position [$F(2.28, 66.13) = 4.017, p = .018$ (Greenhouse-Geisser correction)], indicating that the influence of the total fixation dwell time on the critical object before the change was not equal for all

ordinal fixation positions. From the parameter estimates it is obvious that the effect of the covariate is significant only for the first ordinal fixation position ($t = 3.557$, $p = .001$). This is also illustrated in the scatter plot of the probability of first look at each of the four ordinal fixation positions in relation to the total fixation dwell time on the critical object before the change (Figure 25).

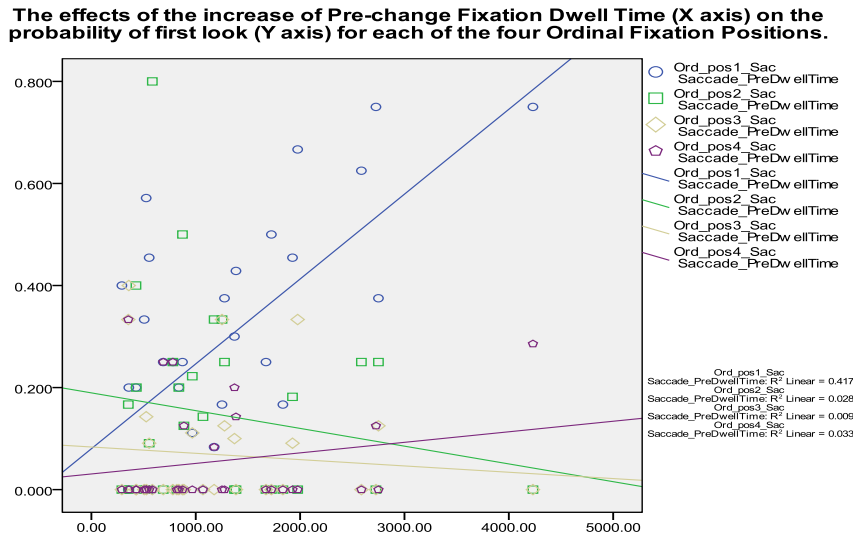


Figure 25: A graph illustrating the differential effect of the covariate of total fixation dwell time on the critical object before the change, which is mainly affecting the first ordinal fixation position (illustrated by the blue line).

These results verify the experimental hypothesis that the direction of orientation change will not affect the critical object's prioritization in the case of the change happening within a fixation, but it will benefit the reverse direction change in the case of it happening within a saccade, which is more prone to memory effects, according to Brockmole & Henderson's (2005a) hypothesis of different mechanisms supporting attentional prioritization for onsets either within a fixation or a saccade. We can assume that the difference found is based on these same memory mechanisms that Brockmole

and Henderson claim support object prioritization in saccade onsets – and in extension orientation changes during a saccade as demonstrated by our series of experiments. Moreover, the difference in prioritization between the abolishment and the creation of a correct action affordance can be accounted for by the duration of the fixations on the critical object before the change, and alternative explanations such as the contribution of motor areas of the brain or a different kind of memory representation are not necessary. Nevertheless this finding is consistent with the well-known fact that increased viewing times enhance the quality of the memory representation, which might be affecting prioritization.

Overall effects of action affordance violations on the deployment of eye-movements.

In Experiment 2.2 additional analyses were performed on a number of eye-movement measures collected during the trial (see Table 6, p. 120). These analyses revealed a number of generic influences of action affordances on eye-movement behaviour. In the present experiment we used the control condition from the previous experiment as a baseline of the probability of looking at a specific object, depending on its correct or incorrect orientation. Such post-perceptual effects of the action affordance of the critical object were adequately analysed throughout the whole duration of the trial in the control condition, as well as in the last half of the trial in the experimental condition of saccade or fixation onsets. The results of those analyses were similar in all these time-windows used. In the present experiment, the half of the trial before the orientation change was identical with the first half in the control condition, so there was no reason to suspect

that there would be any difference, rendering the same analyses unnecessary in this experiment.

DISCUSSION

Our analyses revealed that changes in the orientation of an object which affect its action affordance do cause prioritization in a similar way to the onset of an object in a scene. This prioritization was stronger in the case of fixation changes as compared to saccade changes, in accordance with our previous experiment and the relevant experiments from Brockmole and his colleagues (2005a, 2005b, 2009). Also, similarly with the case of object onsets, this prioritization of the critical object in the case of fixation changes happens quickly, during the first two ordinal fixation positions immediately following the change (probably based on low-level transient motion signals) whereas prioritization due to a saccade change happens slower and is more distributed along the four ordinal fixation positions of our time window. The distribution of both mean fixation probabilities and first look probabilities is almost identical in this object orientation change experiment with the same probabilities in Experiment 2.2, so not only the evidence leads to the same conclusions, but attentional prioritization due to orientation changes seems to be extremely similar with prioritization due to object onsets (see Figure 19 and Figure 20).

Experiment 2.3 also further explored the role of object orientation in attentional prioritization and more specifically in the cases of memory guided prioritization. This experiment demonstrated attentional prioritization following a change of the critical

object's orientation which restores the object to its correct orientation for its normal functioning. Both the abolishment of an action potential and an opposite orientation change which creates a functional orientation can cause the object to be prioritized and lead to further exploration by the observer. Moreover, as hypothesized, it was revealed by the first look probabilities analysis that memory guided prioritization is faster in the case of the creation of a functional relationship as compared to its abolishment. Such a difference in the speed of attentional prioritization is only evident in the case of saccade changes, where prioritization is guided by memory of the scene and the critical object. It seems that the incorrect orientation of the critical object is attracting more fixations in the first half of the trial (before the change) making its encoding in memory more prominent than in the case of correctly oriented objects.

Even in the case of fixation changes which are based on bottom-up mechanisms, there was a different pattern in the distribution of mean fixation probabilities between the two Experimental Groups. In Normal Orientation Changes the peak of mean fixation probabilities was in the 2nd ordinal fixation position, whereas in Reverse Orientation Changes the same peak was in the 1st ordinal fixation position. Even in the case of attention being attracted by oculomotor capture, and even though such capture has been demonstrated to be quite similar regardless of semantic manipulations (Brockmole & Henderson, 2008) or colour changes (Matsukura, Brockmole & Henderson, 2009), action affordance manipulation seems to change the distribution of fixations after the change, with higher probability of fixation (aka attention) to the first ordinal fixation immediately following the change after an incorrect as compared to a correct for the

object's functionality orientation. It was argued that, because of the inclusion of refixations, our measure of mean fixation probabilities can be seen as a measure of distribution of attention rather than speed of attentional prioritization. This difference therefore can be seen as further evidence that initially incorrectly oriented objects are more prominent for encoding in memory, and therefore attention is more readily directed to the critical object after the change even in the case of automatic oculomotor capture.

Our findings support the hypothesis that action affordance violations incompatible with the relevant schema for a critical object's functionality lead to better encoding of the object and to the allocation of a larger part of attentional resources on it. The distance of a perceptual input (and possible motoric activations accompanying it during the process of object recognition) from an action relevant schema might also contribute in object prioritization, but they are not sufficient on their own to manipulate the strength or speed of prioritization, according to the results of Experiment 2.2. Mismatch from the relevant action-schema might originally direct more fixations and attention to a critical object leading to better encoding in memory and greater saliency weight in the online representation of the object. This salient memory representation makes the object easier to be prioritized during memory-guided prioritization compared to a correctly oriented object.

Main Findings Summary

This second series of experiments extended research of action affordance effects on object recognition and memory encoding in real world scenes. At the same time, stimuli

in this series of experiments moved away from objects interaction and addressed more focused questions related to more basic object functionality effects in pre-attentive and post-selection levels of object processing.

Experiment 2.1 demonstrated the success of our action affordance manipulation and its independence from semantic influences, based on an extensive rating of each scene used in our eye-tracking experiments for violations from semantic and functional schemata, as provided by independent judges who were naive to the experimental hypothesis and the aim of our manipulations. These stimuli were consequently used in Experiment 2.2 to test how action affordance violations can be used by the visual system to prioritize a critical object and bring it in the focus of attention. Results indicated that both memory-guided prioritization and oculomotor capture by an onset are independent of its orientation and the subsequent violation of functional schemata, unlike evidence for semantic effects' influences on prioritization (Brockmole & Henderson, 2008). This finding does not provide any support to the hypothesis that motoric activations specific to correctly oriented objects can affect prioritization, or at least that such activations based to the action that an object affords do not have any measurable pre-attentive influence on it. Whether or not such activations of motor areas accompany the visual analysis of an object cannot be tested without relevant neuro-imaging data. Nevertheless, the results from Experiment 2.2 provided evidence that object orientation affected the amount of fixations directed to the critical object and subsequently that attention seems to linger for longer on incorrectly oriented objects as compared to correctly oriented

ones after their onset in the scene (cf. similar effects of semantic inconsistencies, e.g. Henderson, Weeks & Hollingworth, 1999).

Experiment 2.3 provided evidence for attentional prioritization based on orientation changes of an object, introducing either the abolishment of the action affordance of the critical object in the scene, achieved by its change to an inappropriate orientation, or the creation of a functional positioning (useful action affordance) from an original non-functional positioning. This experiment demonstrated that action affordance influences play a role in the memory encoding of an object and the amount of attentional resources devoted to its monitoring. These influences lead to faster memory-guided prioritization after a change of an incorrectly oriented object, an orientation which violates its action affordance, as compared to an initially correct action affordance of a correctly oriented object.

As a conclusion action affordance effects could not be used pre-attentively in Experiment 2.2, demonstrating a difference from the fast influence of gist and semantic expectations. On the other hand Experiment 2.3 demonstrated their post-perceptual influences in attentional prioritization through the manipulation of the degree of violation from a given schema and the prominence of the object representation encoded in memory. Object orientation and functionality information is only relevant to attentional prioritization post-perceptually and not pre-attentively during object recognition. A more extensive general discussion regarding the findings of the series of experiments presented in this chapter, and especially the comparison between Experiments 2.2 and 2.3, will be presented in the next chapter.

CHAPTER 4

EXPLORING PRE- ATTENTIVE AND POST- SELECTION EFFECTS OF ACTION AFFORDANCES IN AN OBJECT PRIORITISATION PARADIGM USING REAL WORLD SCENES.

PART II:
GENERAL DISCUSSION

GENERAL DISCUSSION: Conclusions based on the Comparison of Object Onset and Orientation Change Experiments

The purpose of this thesis was to clarify the role of action affordances in object perception, attention modulation and deployment of eye movements. In our second series of experiments, it was demonstrated that functional positioning manipulations can determine the amount of time to be allocated to an object during free-viewing as well as after unexpected changes to the scene displayed. It was also demonstrated that action affordance manipulations often accompany semantic manipulations, even when not intended; it is therefore difficult to isolate purely semantic manipulations and many previous experiments have not properly accounted for such effects. Finally, although most of the action affordance effects were found to affect post-selection mechanisms rather than being pre-attentive, it was demonstrated that action affordances of the objects in a scene are part of the feature information extracted from the scene and can be therefore utilized by scene memory mechanisms to guide attention.

These experiments add to the discussion about object consistency within the scene context, a topic where there has been contradicting evidence about the effect of semantic inconsistencies on object detection and identification. In this thesis we also looked at other kinds of inconsistency, namely orientation based action affordance violations, which partly show similar effects but also have differences from violations of semantic

consistencies, as traditionally studied in related research. Many researchers have demonstrated better detection of extrafoveally presented semantically consistent objects as compared to inconsistent ones (Biederman, Mezzanotte & Ravinowitz, 1982; Boyce, Pollatsek & Rayner, 1989). The perceptual advantage observed for objects that appear in semantically consistent contexts has been hypothesized to arise from expectations that the context implies. In other words, activation of a scene schema could provide information about the objects and their component features likely to appear in the specific scene (Friedman, 1979).

Object position and orientation information should also be part of scene schemas, especially in our series of experiments where the orientation manipulations had a detrimental effect in the object's functionality or action affordance within the scene. These features are part of the maintained online representations generated during viewing of scenes or arrays of objects (Aivar, Hayhoe, Chizk & Mruczek, 2005; Henderson & Hollingworth, 1998a, 2003; Hollingworth, 2004, 2006, 2007; Hollingworth & Henderson, 2000, 2002; Smilek, Eastwood & Merikle, 2000; Tatler, Girlchrist & Rusted, 2003). In a long term memory experiment, for example, orientation changes were also reported at a well above chance accuracy, similarly with token changes (Hollingworth 2005b).

Viewpoint effects in novel object recognition (Tarr, Bulthoff, Zabinski & Blanz, 1997; Tarr, Williams, Hayward & Gauthier, 1998) and negative priming of nonsense shapes (DeSchepper & Treisman, 1996) also indicate that familiarity-based orientations create schemata that can subsequently guide object recognition. In our series of

experiments, not only did Experiment 2.2. reveal no pre-attentive differences between functionally consistent and inconsistent objects (action affordance manipulation), but when post-selection mechanisms were further probed in experiments 2.3 and 2.4, there was faster object prioritization for initially inconsistent action affordances (incorrect orientation before the change) as compared to consistent ones. Even though the task in our experiment was not target finding, these results align with findings that inconsistent objects are more easily detected in brief displays (Hollingworth & Henderson, 1998, 2000) and they are more likely to initially attract attention (Gordon, 2004).

Matsukura and her colleagues (Matsukura, Brockmole & Henderson, 2009) demonstrated that in the case of memory guided prioritization, change to the colour of an object is as conspicuous as the change produced by the onset of an entirely new object. It was hypothesized that sudden colour changes require the observer to create a new object file in visual working memory (Treisman & Gelade, 1980). Recent evidence, however, has suggested that surface features such as colour may not determine object files (Mitroff & Alvarez, 2007). It therefore seems possible that prioritization is at least partly facilitated by the low-level mismatch between the stored image and the new coloured object. However, the same experiment demonstrated that prioritization was not affected by the visual salience of the colour of the critical object itself, so these results were not based solely on low-level characteristics. Nevertheless, colour changes entail a quite noticeable difference in the appearance of the critical object. The action affordance manipulations in this series of experiments on the other hand kept the low-level mismatch between the image before and after the onset or change to a minimum. This is

another indication that memory-guided object prioritization is rather contingent on schema-based violations and the mismatch from online memory representations.

The comparison of the findings of Experiments 2.3 and 2.4 supports our hypothesis that action affordance inconsistencies have an effect on memory guided prioritization and specifically that action affordance violations lead to faster object prioritization. These results are consistent with the visual memory theory of scene representation (Hollingworth & Henderson, 2002), according to which visual representations are preserved after withdrawal of attention and accumulated to form a relatively detailed scene representation (Hollingworth, 2003). The prominence of the representation of the object affects the detection of an orientation change. It is the mismatch between the perceptual input and the online representation that triggers the attentional prioritization for the critical object.

There has also been evidence that these visual representations stored over seconds of scene viewing are not sensory (or iconic) in nature (see Irwin, 1992 for a review), because these representations (i.e. iconic memory) decay within a few hundred milliseconds after a stimulus event (Averbach & Coriell, 1961; Di Lollo, 1980; Irwin & Yeomans, 1986; Sperling, 1960) and are not integrated across disruptions such as saccadic eye movements (Grimes, 1996; Henderson & Hollingworth, 2003; Irwin, 1991). These representations rather consist of more durable higher level object representations abstracted away from precise sensory features and maintained in VSTM and LTM (Biederman & Cooper, 1991; Carlson-Radvansky & Irwin, 1995; Henderson, 1997; Irwin, 1991; Phillips, 1974; Pollatsek, Rayner & Collins, 1984). Although these

representations do not retain in full the precision of a sensory representation such as absolute spatial coding (Irwin, 1991; Phillips, 1974) or veridical representation of object contours (Henderson, 1997; Henderson & Hollingworth, 2003c), they are detailed enough to code object token (Henderson & Hollingworth, 2003a; Henderson & Siefert, 1999, 2001), object orientation (Henderson & Hollingworth, 1999b, 2003a; Henderson & Siefert, 1999, 2001) and structural relationships between object parts (Carlson-Radvansky, 1999; Carlson-Radvansky & Irwin, 1995).

Our conclusion that action affordances are part of scene memory representations was demonstrated by enhanced object prioritization when an incorrectly oriented object is changed to a correct orientation (Experiment 2.4) as compared to the opposite direction of the change (Experiment 2.3). This is compatible with the suggestion that representations supporting object recognition can be of sufficient specificity to code individual exemplars and object orientations (Tarr & Bülthoff, 1998). The neural basis for encoding such information could be in the visual cortex, where various neural maps code visual features such as orientation, shape or motion (DeYoe & van Essen, 1998). These maps, in conjunction with maps in the frontal cortex coding for direction, distance and force of intentional actions (Hommel & Elsner, 2009), can provide the basis of the co-ordination between perception and action systems. A mechanism by which people might spontaneously integrate the features of visual events into episodic structures that are re-activated if their ingredients match aspects of the current input has been suggested by a dual-process feature-integration model which distinguishes between ad hoc binding and conjunction detection (Hommel & Colzato, 2009).

A way that the reported action affordance consistency manipulations as well as similar semantic consistency manipulations (Brockmole & Henderson, 2008) could have an effect on object prioritisation is by modulating the active process of building the visual representation of the scene. It is well-known that during online viewing, as the eyes and attention are oriented within a scene, higher level representations are formed for attended objects. Visual representations of each object are then indexed to a position within the spatial representation of the scene and transferred from VSTM to LTM, where they are retained and augmented with visual representations from other previously attended objects (Henderson & Hollingworth, 1998a; Hollingworth, 2003, 2007). The importance of spatial characteristics of the scene and the layout of the objects within it has been demonstrated by many researchers recently through the contextual cueing paradigm, which showed that during both visual short term memory (VSTM) and long term memory (LTM) retrieval, performance is poorer when the spatial configuration of an array of objects is changed or when the context is removed or altered (Brockmole & Henderson, 2006; Chun, 2003; Chun & Jiang, 1998; Jiang, Olson & Chun, 2000; Vidal, Gauchou, Tallon-Baudry & O'Regan, 2005). Visual representations of an object are reactivated when attention is allocated back to the position where the object was bound during viewing; this influences the ongoing perceptual processing of the scene and supports accurate memory performance, such as change detection (Henderson & Hollingworth, 1999b; Hollingworth & Henderson, 2002).

This idea is compatible with the “object file theory” according to which various characteristics of an object during online processing are bound together in an object file (Henderson, 1994; Kahneman, Treisman & Gibbs, 1992; Treisman and Gelade, 1980).

In a similar way Hollingworth and Henderson (2002) suggested that the outcome of the online processing of an object within a scene among various ordinal fixations could be a “long term memory object file”. Our object orientation change paradigm also demonstrated the importance of having fixated the critical object before the change; in our object prioritization analysis we needed to clean up our data from cases where the critical object had not been fixated before the change to reduce noise.

Many of the experiments which have reported change blindness did not include measures of tracking eye movements, so the way that attention has been distributed during viewing might have been a confounding factor leading to change blindness demonstrations. It is possible that the critical object had not been previously fixated or focally attended before the change, since transfer of visual information into memory is strongly dependent on the allocation of visual attention and the eyes (Averbach & Coriell, 1961; Currie, McConkie, Carlson-Radvansky & Irwin, 2000; Henderson & Hollingworth, 1999b; Hollingworth & Henderson, 2002; Hollingworth, Schrock & Henderson, 2001; Irwin, 1992a; Irwin & Gordon, 1998; McConkie & Currie, 1996; Nelson & Loftus, 1980; Schmidt, Vogel, Woodman & Luck, 2002; Sperling, 1960). On the other hand, in the object prioritization experiments where eye movements was one of the primary measures, onsets (Boot, Krammer & Peterson, 2005; Brockmole & Henderson, 2005a; Irwin, Colcombe, Kramer & Hahn, 2000; Theeuwes, Kramer, Hahn & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin & Zelinski, 1999; Yantis & Jonides, 1984), offsets (Brockmole & Henderson, 2005b; Theeuwes, 1991) and also feature changes (Irwin et al, 2000; Matsukura, Brockmole & Henderson, 2009) have been found to attract attention.

Even in more realistic situations, it has been demonstrated that context can help people monitor their environment in a strategic manner and handle unexpected events (Karacan & Hayhoe, 2008; Rothkopf, Ballard, Sullivan & de Barbado, 2005; Sprague & Ballard, 2007). Observers are able to learn the dynamic properties of an environment to distribute their gaze in an optimal manner (Hayhoe & Ballard, 2005; Hayhoe, Droll & Mennie, 2007). Action affordances could easily be part of these dynamic properties. Functional positioning effects could be bound in a schema based on semantic knowledge about an object, familiarity of a specific orientation of the object allowing for its normal use at a given context (or most contexts in general) and also procedural memory and activation of motor areas during handling of the specific object. We hypothesise that this is the reason for both the similarities and differences of the effects of action affordances as compared to effects of semantics in the object prioritization paradigm we used. Our research demonstrates that action affordances and object functionality schemata could contain knowledge about the semantics of the object but also procedural knowledge about its function and motor experiences from its use (Humphreys & Riddoch, 2007).

In accordance with the long term memory object file hypothesis (Hollingworth and Henderson, 2002), functional positioning, as manipulated in our experiments by correct and incorrect orientations, played a central role in the mismatch of the comparison of the scene after the onset or change with the stored representation of the critical object built before the change. Rao and Ballard (1999) hypothesized that this mismatch may serve as a basis for attracting attention to changed regions in scenes. Our findings from the comparison of experiments 2.3 and 2.4 corroborate this hypothesis. Scenes starting with the critical object in an incorrect orientation are already violating the schema of the

familiar orientation for its correct use, leading to better encoding of the object. This modulates the weight of the orientation feature and the prominence of the encoding in memory of the critical object before the onset or change. This prominence increases the “residual” signal of the comparison of the online representation of the scene after the change with the stored scene representation. A possible way for such a comparison of the scene with its stored representation during online processing can be found in models of early cortical processing, where feedback signals from higher cortical areas carry a model-based prediction to lower areas (Rao and Ballard, 1999).

In the case of a mismatch between input and top-down predictive signals, the residual signal is transmitted to higher cortical areas and generates a revised prediction. If the predictive signal is based on a stored memory representation of the scene, scene changes may generate a mismatch or residual signal that prompts a re-evaluation of the scene and may thereby attract attention (Brockmole & Henderson, 2005b; Karacan & Hayhoe, 2008; Matsukura, Brockmole & Henderson, 2009). Such a mechanism could be supporting both the semantically inconsistent advantage in previous similar experiments (Brockmole & Henderson, 2008; Karacan & Hayhoe, 2008) as well as the functionally inconsistent object advantage in our series of experiments and could be supplementing the job of analogous saliency-based models, by allowing attentional deployment to regions that are not part of the ongoing task and where something unexpected might occur. Itti & Baldi (2005) also proposed a similar notion of Bayesian “surprise” but this surprise was measured with respect to the stimulus properties, instead of the memory representation as suggested by Karacan and Hayhoe (2008).

Our experiments demonstrated faster object prioritization in the cases of action affordance violations in the object orientation change experiments (Experiments 2.3 & 2.4). Semantically inconsistent objects were also found to be fixated sooner than semantically consistent ones during memory guided prioritization (Brockmole & Henderson, 2008). Both of these findings can be explained by a “memory schema” having an effect on object prioritization during saccade changes. According to the “memory schema hypothesis”, information about semantically (Hollingworth & Henderson, 1998) or functionally (Experiment 2.4) inconsistent objects is preferentially remembered after perceptual encoding. Opposite to information about objects which are consistent with the scene, which may be lost during a normalisation process within a memory schema, information about inconsistent objects may be retained more veridically, perhaps as part of a list noting deviations from default values in the schema (Friedman, 1979).

On the other hand, onsets or changes during a fixation seem to be based on a different top-down mechanism, which takes advantage of low level disruptions such as the transient signal of the onset or change. Such disruptions are detected much faster than the time required for a memory representation or a relevant schema to be activated. In Brockmole and Henderson’s previous experiment (2008) as well as in our current experiments, prioritization of objects which appear (or whose orientation is changed) during a fixation were not modulated by semantic or action affordance consistency influences. This is not absolute though and our results give a hint that both mechanisms could be activated at the same time, although at different speeds.

From the comparison of Experiments 2.3 and 2.4, a difference was demonstrated between normal and reverse orientation changes during a saccade, in the probability of first look at the first ordinal fixation position immediately following the object orientation change. The same comparison between normal and reverse orientation changes during a fixation showed a trend quite close to significance, although not as easy to detect as in the case of changes during a saccade, for their difference in the second ordinal fixation position following the change. This effect might be a combination of oculomotor and memory guided prioritization.

For changes during a fixation, the majority of eye movements directly following the change could have been attracted to the critical object by the transient signal. In some fewer cases, where the transient signal did not immediately capture attention for some reason, it could be the case that memory guided prioritization had adequate time to also be initiated and led to attentional prioritization of the object at the next possible ordinal fixation position. The differences in the speed of oculomotor and memory guided prioritization was demonstrated in the findings of the older experiments on attentional prioritization in real world scenes (Brockmole & Henderson, 2005a, 2005b, 2008; Matsukura, Brockmole & Henderson, 2009) and further supported by our findings. What is suggested is that these two mechanisms need not necessarily be independent of each other, but they could also operate in synch. Since memory guided prioritization operates less strongly but is spread more equally among the few initial fixations following an onset (Experiments 2.2; cf. Brockmole & Henderson, 2005a) or a feature change of an

object (Experiments 2.3 and 2.4), this mechanism could take over in the case of partial failure of top-down oculomotor capture.

Additionally, the lack of an effect of action affordance consistency after an onset in first look probabilities in Experiment 2.2, in conjunction with baseline differences in fixation probabilities between functionally consistent and inconsistent objects, provides evidence in favour of an “attention hypothesis” suggesting that perceptual encoding of functionally consistent and inconsistent objects is not influenced directly by the scene context. But after the object has been identified, attention is preferentially allocated to objects that violate the constraints imposed by scene meaning as well as relevant schemas (Hollingworth & Henderson, 1998). Our baseline differences are in line with evidence that once a semantically (or functionally) inconsistent object in a scene is fixated, eyes tend to dwell longer on that object compared to consistent objects (De Graef et al, 1990; Friedman, 1979; Henderson, Weeks & Hollingworth, 1999; Loftus & Mackworth, 1978). Loftus and Mackworth (1978) even claimed, based on their results, that eyes may be drawn to inconsistent objects in the periphery. Such a result though has not been replicated with more realistic stimuli at more recent experiments (De Graef, Christiaens & d' Ywalle, 1990; Friedman, 1979; Henderson et al, 1999a; Henderson & Hollingworth, 1998a)

The results of experiments 2.2, 2.3 and 2.4 collectively support the “functional isolation hypothesis” put forward by Hollingworth and Henderson (1998), and add to this hypothesis that object identification processes may be isolated from contextual as well as functional information related to the scene. The effects of action affordances do

not seem to be in position to affect object prioritization pre-attentively (experiment 2.2). However, once an object representation has been formed, the functional positioning of that object within the scene may influence memory for that object or the allocation of visual/spatial attention. This leads to enhanced representation of functionally inconsistent objects, which consequently leads to their faster prioritization. A possibility for the lack of an effect of action affordances in our onset experiment (experiment 2.2) might simply be that the action affordance activations are not relevant for tasks other than object identification, so, in the object prioritization paradigm where object identification is not explicitly set as the task, action affordances are not in position to show any effects. Although our task was more close to free viewing rather than object identification, as in the experiments which demonstrated identification to be independent of the semantic consistency of the object with regard to the scene it is situated in (Hollingworth & Henderson, 1998), our paradigm showed that action affordance effects do influence attention and encoding in memory, rather than pre-attentive perceptual processes.

Another explanation for the lack of an action affordance effect making the prioritization of objects onset in an incorrect orientation more readily detected than in the case of correct orientation, could be related to the lack of the intention for an actual action. Many of the earlier experiments using reaction times or performance accuracy, as measures of action affordance effects on perception, included the execution of an actual action (Bekkering & Neggers, 2002; Meegan & Tipper, 1998; Müsseler & Hommel, 1997a, 1997b; Tipper, Lortie, Baylis, 1992). It could be the case that these paradigms are

qualitatively different from our attention capture paradigm, and that these effects can only be demonstrated when an actual action is executed. On the other hand, there is some evidence for effects of action affordances independent of an intention to act (Ellis & Tucker, 2000; Phillips & Ward, 2002; Tucker & Ellis, 1998, 2004; Tipper, Paul & Hayes, 2006; Symes, Ellis & Tucker, 2007). However, even in these cases, orientation of the object was part of the participant's task or somehow relevant to it, or in general attention was guided to characteristics of the stimuli that define their usability, to be able to demonstrate action affordance effects.

It is difficult at this point to estimate whether there are specific requirements of an action to be executed or some kind of attention priming towards specific features of a stimulus to allow for action effects to be demonstrated, but there is definitely evidence that this could be the case. In an experiment by Linnell and his colleagues (2005) objects were artificially created by perceptual grouping of neighbouring entities based on low level features (specifically drawing of connecting 'tubes' creating dumb-bell type stimuli). Differences on what is coded as a perceptual object, which consequently affected attention, were revealed. But when an action (pointing movement) was programmed towards the object, effects of perceptual grouping on selection were overruled. The results of this experiment suggested that pointing either emphasizes spatial selection at the expense of object-based selection, or changes the nature of the representation(s) mediating perceptual selection.

In general, it seems that different action intentions alter the information that we respond to in visual displays, and the way objects are coded (Fischer and Hoellen, 2004;

Humphreys & Riddoch, 2007; Humphreys, Riddoch, Linnell, Punt, Edwards & Wing, 2005; Linnell, Humphreys, McIntyre, Laitinen & Wing, 2005; Schiegg, Deubel & Schneider, 2003). Moreover, differential pre-saccadic activation of neurons in the supplementary eye-field during a saccade-only condition versus a saccade-and-reach condition suggests that these neurons are involved in signalling whether the motor task is oculomotor or combines eye and arm movements (Mushiake, Tanatsugu & Tanji, 1997). Nevertheless, this evidence suggests that we should be careful when combining different experimental paradigms to draw conclusions about action affordances.

The distinction regarding the different influences of action affordances in instances of an intended or no intended action seems to refer back to the differences in the definition of the concept of action affordance between Gibson and Norman. In Chapter 1 it was described how Gibson's (1977, 1979) definition of affordance focuses only on the action capabilities of an actor and not on perceptual and mental capabilities like Norman's (1988, 1990). Gibson defined affordances as independent of culture, prior knowledge or expectations of the actor (unlike Norman) but still accepted that the information that specifies the affordance is dependent on the actor's experience and culture. This conceptual distinction could be a useful guide in our experimental efforts to measure effects of action affordances on visual perception. It might be the case that many kinds of affordances can be utilised by the visual system but based on different mechanisms. The sub-group of experiments which study action affordances independent of an actual action or experiments that introduce terms like Pure Physical Affordances (PPA: Symes, Ellis & Tucker, 2007) might be tapping more on the generic definition of affordances by

Gibson. Evidence from patients demonstrating utilisation behaviour supports such a definition of action affordances, because this behaviour seems to be automatically invoked independently of the understanding of the task set from the patient (Lhermitte, 1983).

On the other hand, the sub-group of experiments which studied action affordances before, during or after the execution of an action might be taping more on the definition of Norman with action affordances conditional on higher-level goals or conceptual knowledge. Tucker and Ellis (1998), for example, described the actions afforded by a visual object as intrinsic to its representation, departing from Gibson's view of direct detection of affordances for action without the need for intervening processes. Experiments from Riddoch and her colleagues which revealed utilization errors only in the case that the task involved grasping an object, but not when the task was pointing at the object (Riddoch, Edwards, Humphreys, West & Heafield, 1998; Riddoch, Humphreys & Edwards, 2000), support the view that object affordance in the same scene can be modulated by the action intentions of the observer. Explicit definition of the notion of action affordances, as well as caution in hypothesizing under which conditions effects of action affordances can become evident, are required.

CHAPTER 5

CONTRIBUTIONS OF OUR
FINDINGS TO THE
DISCUSSION RELATED TO
CONTEXT, GIST AND
ATTENTION.

CONTEXT, GIST & ATTENTION

Contextual Effects & Gist

In the thesis introduction in Chapter 1 it was mentioned that the current thesis and the findings from our experiments also relate to the discussion about the contents of visual working memory and their organisation. It is now well known that global structural information in a scene (gist), such as basic-level category of the scene (Potter, 1976), spatial layout (Schyns & Oliva, 1994) or action affordances (Green & Hummel, 2006), can have an almost instantaneous effect on various aspects of perception such as object detection, attention deployment as well as gaze control in cluttered scenes (Oliva, Torralba, Castelhana & Henderson, 2003; Torralba & Oliva, 2003). Gist effects can be observed as fast as 100 msec after the presentation of the scene.

Gist effects are thought to be a result of an automatic activation of a framework of semantic information. Such information includes scripts such as the actions occurring in a scene (Friedman, 1979), scene related knowledge such as the typicality or familiarity of a particular scene, as well as predictions of which objects are likely to be found in the environment. The presence of a particular object, for example, constrains the identity and location of nearby objects, a property that can be used by the visual system to generate strong expectations about the probable presence and location of other objects (Oliva & Torralba, 2007). The term gist therefore refers both to perceptual as well as conceptual gist. The former refers to the structural representation of the scene built

during perception whereas the latter refers to semantic information inferred while viewing the scene or shortly after the scene has disappeared from view. This second type of gist is constantly enriched and modified as perceptual information is accumulated, from early to later stages of visual processing (Oliva, 2005).

Similarly, contextual cueing experiments have demonstrated that various object features such as spatial information are coded in relation to the rest of the array or scene. There has been evidence that the invariance of the spatial configuration of an array of objects or a scene can have an effect on the detection of features of individual target objects, whether it is only two items surrounding the target or the entire display that is repeated (Brady & Chun, 2007; Brockmole, Castelano & Henderson, 2006; Brockmole & Henderson, 2006; Chun & Jiang, 1998, 1999; Jiang & Chun, 2003; Song & Jiang, 2005). For example, disappearance of non-targets during a blank screen interval or change of their configuration was found to decrease performance in detecting a colour change of a cued target object (Jiang, Olson & Chun, 2000). Similar effects have been reported both in VSTM (Jiang, Olson & Chun, 2000) and in a LTM experiment regarding face features (Tanaka & Farah, 1993). Relational information has even been considered so important in experiments following up on these initial demonstrations of contextual cueing that a broadening of the parallel store model of visual short-term memory (Wheeler & Treisman, 2002) was suggested, to include “structural gist” (Vidal, Gauchou, Tallon-Baudry & O’Regan, 2005).

These contextual cueing effects could be a result of an arbitrary binding of higher level visual representations formed for attended objects and scene positions during the

allocation of attention and eye movements within the scene (Henderson, 1994; Hollingworth, 2005; Irwin & Zelinsky, 2002; Kahneman, Treisman & Gibbs, 1992; Zelinsky & Loschky, 2005). Fixation of an object at a particular location is known to simultaneously activate medial temporal codes for its position as well as selectively activate IT representations coding the visual form of that object (Rolls, Aggelopoulos & Zheng, 2003; Sheinberg & Logothetis, 2001). Visual object representations maintained in infero-temporal (IT) brain regions (Logothetis & Pauls, 1995; Logothetis & Sheinberg, 1996; Tanaka, 1996) and spatial scene representations in medial temporal regions (Aguirre, Zarahn & D'Esposito, 1998; Burgess, Maguire & O'Keefe, 2002; Chun & Phelps, 1999; Epstein & Kanwisher, 1998; O'Keefe & Nadel, 1978) could be bound efficiently through auto-associative mechanisms that have been proposed to support episodic binding in the hippocampus (Marr, 1971; Treves & Rolls, 1994). Impairment in association learning between individual object locations and spatial context following medial temporal damage (Chun & Phelps, 1999) as well as evidence of object-position binding deficits in hippocampal amnesic patients, both over delays implicating LTM and over delays implicating STM (Hannula, Tranel & Cohen, 2006; Olson, Page, Moore, Chatterjee & Verfaellie, 2006), suggest that spatial structure in VSTM and LTM both depend on medial temporal binding mechanisms.

This linking of scene-specific hippocampal – parahippocampal place cells codes and IT object representations (for a review see Rolls, 1999) could be consequently supporting episodic scene representations (Hollingworth, 2006). The model proposed by Hollingworth is similar to models of landmark-position binding in the rodent navigation

literature (Gallistel, 1990; McNaughton, Barnes, Gerrard, et al., 1996; Redish & Touretzky, 1997). It has been demonstrated that humans can reliably remember binding of object identity and position within real world scenes (Diwadkar & McNamara, 1997; Hollingworth, 2005; Irwin & Zelinsky, 2002; Rieser, 1989; Shelton & McNamara, 2001; Zelinsky & Loschky, 2005) and similar effects have also been found for nonsense stimuli in VSTM experiments (Henderson & Siefert, 2001; Irwin & Andrews, 1996; Jiang, Olson & Chun, 2000; Kahneman, Treisman & Gibbs, 1992). Contextual spatial structure could similarly be abstracted away from properties of objects occupying each location in the configuration (Chun & Jiang, 1998).

Evidence from research on gist effects in object recognition as well as contextual cueing paradigms have led to a shift from the framework of a hierarchical organisation of modules of increasing complexity (edges, surfaces, objects) with the highest level of object identification eventually initiating scene schema activation (Marr, 1982), to more parallel models, predicting that a scene may be initially processed as a single entity with its segmentation in objects appearing at a later stage during gist formation (Hoiem, Efros & Hebert, 2008; Oliva, 2005). According to this view, the overall layout of a scene is ascertained very rapidly, with finer details filled during later allocation of attention (Biederman, 1981). Some of this semantic meaning should be attached during a rapid “gist” labelling and the overall spatial mapping of the scene during the first few hundred msec of viewing (Potter, 1975, 1976), with semantic information linked to objects and organised extremely rapidly (Walter & Dassonville, 2005). In a similar spirit, recent computational models of attention have moved from low-level saliency based models

(Itti, Koch & Niebur, 1998) towards the idea that scenes are analyzed by two parallel pathways: a local pathway, where each spatial location is assessed independently, image saliency is computed and object recognition performed, and a global pathway, where the entire image is processed by extracting global statistics as well as computing expected location of the objects in the image (Itti & Koch, 2001; Torralba, Castelhano, & Henderson, 2006).

The provision for the role of scripts, such as the actions occurring in a scene (Friedman, 1979) in the gist literature mentioned above, as well as the role of spatial layout and object features such as orientation in the contextual cueing experiments, are compatible with the evidence from our series of experiments about action affordances being part of the scene representations in VWM as well as the LTM object files (see also Hollingworth & Henderson, 2002). Relational information is particularly important in the case of action affordances, as manipulated in our experiments, because object orientation information is not independent from the context of the rest of scene and the positioning of other objects. This idea, that the orientation of an object in relation to local and global scene context is an important indicator of action affordance consistency, is compatible with the suggestion that online representations created during scene viewing are abstract (Biederman & Cooper, 1991; Carlson-Radvansky & Irwin, 1995; Davenport, 2007; Henderson, 1997; Irwin, 1991; Mandler & Parker, 1976; Vidal, Gauchou, Tallon-Baudry & O'Regan, 2005; Phillips, 1974; Pollatsek, Rayner & Collins, 1984).

It has been demonstrated, for example, that when there is a large number of similar objects that do not fall into pre-grouped categories or when there are not enough attentional resources for the encoding of the characteristics of individual elements, humans encode the statistical properties of a display (such as mean size or object location of individual items) rather than properties of the individual elements which compose that display (Alvarez & Oliva, 2008; Ariely, 2001; Ariely & Burbeck, 1995; Chong & Treisman, 2003, 2005a, 2005b). In this case, representation of a set as a whole might be easier than representation of the individual elements. This evidence suggests that visual information can be represented at multiple levels of abstraction, from local details to abstract features that summarize the local details (Alvarez & Oliva, 2008). This abstract nature of the scene representation does not necessarily mean that configural representations maintain only the abstract spatial layout of occupied locations (Jiang, Olson & Chun, 2000), but that information about individual objects bound to those locations (Hollingworth & Henderson, 2002) as well as episodic scene representations such as direct object-to-object association (Davenport, 2007) are also included. Stimuli from other perceptual and cognitive systems (such as semantic or motor codes) could also be bound within multimodal representation of an environment (Hollingworth, 2007).

Semantic consistency manipulations have been easy to demonstrate but contextual effects are not necessarily confined in semantic effects. The similarity of our action affordance manipulations with semantic manipulations (Brockmole & Henderson, 2008) as well as the speed of their effects in the attentional prioritization paradigm reveals that

these action affordance effects might also be based in semantic-like effects of functional positioning of the objects in the scene. For example, in target detection tasks, it has been demonstrated that both semantic (object presence, position and size) and physical (consistent support and interposition with other objects) object-scene relationships have an impact on performance within a temporal window of a glance (<200 ms) (Biederman, Mezzanotte & Rabinowitz, 1982; Hock, Gordon & Whitehurst, 1974). The context provides a robust estimate of the probability of an object's presence, position and scale (Eckstein, Drescher & Shimozaki, 2006; Hoiem, Efros & Hebert, 2008; Peters & Itti, 2006; Torralba, 2003).

The difference between functionally consistent and inconsistent objects in attracting attention as demonstrated from the comparison of experiments 2.3 and 2.4, in conjunction with similar results showing better long term memory for semantically inconsistent as compared to consistent objects in a scene after an initial free-viewing session (Friedman, 1979; Pedzek, Whetstone, Reynolds, Askari & Dougherty, 1989), give support to a memory schema hypothesis. Object representations that are semantically or functionally consistent with a stored memory schema for that type of scene could be normalised to the default values in the schema, whereas inconsistent object representations could be retained in a more veridical form (Hollingworth & Henderson, 2000). On the other hand, some researchers have noted that these differences in free viewing tasks could be arising from increased foveal processing time and not differences in memory processing per se (Biederman, Mezzanotte & Rabinowitz, 1982; Henderson, 1992).

The amount of time spent on functionally consistent and inconsistent objects did show a trend towards a significant difference in our baseline analyses. At the same time, the lack of an action affordance effect on object prioritization in our onset experiment (experiment 2.2) does not support an attentional attraction hypothesis. Such a hypothesis would predict that covert attention is pre-attentively drawn to an object that does not fit to the schema of the specific type of scene (or object functionality). Subsequently, attentional resources would produce a more complete or better remembered perceptual description and facilitate change detection performance compared to consistent objects. Research which similarly failed to provide support for such a hypothesis has shown eyes to not be initially drawn to semantically inconsistent objects (De Graef, Christiaens & d'Ywalle, 1990; Henderson, Weeks & Hollingworth, 1999).

Our results are more in line with an attentional disengagement hypothesis supporting that although attention is not initially drawn to regions of conceptual difficulty, once such a region has been attended, attention may be captured by this conceptual processing difficulty (Antes, 1974; Henderson & Hollingworth, 1998a, 1999a; Henderson, Weeks & Hollingworth, 1999; Mackworth & Morandi, 1967). The role of attention in relation to our action affordance manipulation and object prioritization in general is further discussed in the section below.

Attention – Prominence in Memory Encoding

It has been suggested that changes to regions of high interest are more quickly detected than changes of least interest (Rensink, O'Regan & Clarck, 1997). These areas are preferentially attended and visual information about them is more likely to be retained across a retention interval (Scholl, 2000). Semantic properties of an object were found to be influencing whether the representation of that object will be maintained between views of a scene. However, this influence is not caused solely by differential allocation of eye fixations to the changing region. Inconsistent objects were more accurately detected even during a single cycle of sequence, as in the case of a flicker - change detection paradigm where eye movements have been eliminated (Hollingworth & Henderson, 2000).

Similarly, in clinical cases of neglect patients, directed action towards an object has been reported to induce bias to attend the specific object and this modulation is even strong enough to override the bias induced by damage to parietal areas. It has been found for example that neglect of the left side can be reduced, when patients orient their trunk and/or head towards the left, even when the eyes remain centrally fixated (Ward, 1999). Similar benefits come from directing an action towards the contralesional space; for example clenching the hand contralesionally to the neglected side improves performance during cancellation (Robertson & North, 1994) or walking (Robertson, Tegner, Goodrich & Wilson, 1994). Therefore it seems that biases to attend to an object induced by action have the ability to focus processing of objects in exactly the same

manner as biases induced by templates for target, colour, shape or location (Ward, 1999).

Such action-based facilitation of perception could even provide an alternative account of the findings on the famous patient DF (Goodale, Milner, Jakobson & Carey, 1991). These findings need not necessarily rely on representational differences between the ventral and dorsal system, but they could be accounted for by a single representation of object shape, with directed action towards the target facilitating its processing (Ward, 1999). Moreover evidence such as the action affordance effects being observed when the task is object shape discrimination but not colour discrimination, imply that action affordance effects are not totally automatic, but are rather determined by the stimulus properties of the object that is attended. Responses need to be compatible with the evoked action, for motor representations such as grasping actions to be spontaneously facilitated, and attention must be focused on action-relevant features of the object, such as shape (Tipper, Paul & Hayes, 2006).

Our results from the analysis of the baseline condition as well as the part of the trial before the onset or object orientation change are consistent with the hypothesis that action affordances modulate the distribution of eye movements and attention. This modulation consequently favours the prominence of the functionally inconsistent objects and their representation in VWM and LTM. The superiority of functionally inconsistent objects in attracting attention was demonstrated by more fixations and longer time spent on fixating incorrectly oriented objects within a trial. There were also larger run count and longer first pass gaze durations for correctly oriented objects. First pass gaze

durations, which code for the sum of the durations of all fixations between first entry and first exit in a target object region, have been traditionally considered to be a good measure of the time required to process semantic inconsistencies (de Graef, Christiaens & d' Ywalle, 1990; Friedman, 1979; Loftus & Mackworth, 1978; Vo & Henderson, 2009). This effect therefore indicated that our action affordance manipulations also have a similar effect with semantics in regard to the assignment of saliency to the object and the attentional resources required for its processing.

Finally, the relevance of attention in the exploration of action affordance effects in the present thesis became evident through the differences between pre-attentive and post-selection effects of action affordances. Spatially parallel ‘pre-attentive’ processes are often assumed to group and segment the visual world before passing their results on to spatial attention systems (Treisman, 1988, Wolfe, 1994). Although there is evidence of “pre-attentive” grouping on spatial selection specifically (Humphreys, 1998; Prinzmetal, 1981; Prinzmetal and Millis-Wright 1984; Rensink & Enns, 1995; Ward, Goodrich & Driver, 1994) other research indicates that even grouping based on bottom-up similarity can be modulated by spatial attention (Ben-Av, Sagi & Brown, 1992; Mack, Tang, Tuma, Kahn & Rock, 1992), arguing against a state of “pre-attentive” processing separate and prior to “attentional” processes (Ward, 1999).

An alternative way of thinking about this issue is to use an explanatory reference frame where each independent system in the brain interacts with all the others and there is no terminal output stage of processing. In the case of object recognition for example, instead of distinguishing between ‘pre-attentive’, ‘attentional’, or ‘post-attentional’

processes, we can imagine “a continual and developing selectivity, beginning with parallel processing for all objects across all systems, and converging in a stable state in which a single object and action are dominant throughout” (Ward, 1999, p.328). Nevertheless, the separation of pre-attentive features from attention seems to be questionable and overt responses to ‘pre-attentive features’ seem likely to be an attention demanding process (Ward, 1999). The fact that pop-out orientation targets are not detected during the period of the attentional blink for example (Joseph, Chun & Nakayama, 1997) supports such a hypothesis.

By comparing action affordance interference during object onsets against interference during object orientation changes we could differentiate between pre-attentive and post-selection mechanisms. Our results indicate that although there is no evidence of pre-attentive modulation of object prioritization, action affordances do have an effect in post-selection mechanisms, with functionally inconsistent objects attracting attention faster and affecting the encoding of an object in the scene representation during memory guided prioritization but not during oculomotor capture. Our results also support the existence of two separate mechanisms for object prioritization, a bottom-up mechanism of oculomotor capture and a top-down mechanism of memory guided prioritization (Brockmole & Henderson, 2005a, 2005b). It is possible, though, that these mechanisms are not necessarily activated independently but they can work together, although at different speeds, to help achieve object prioritization even in cases where transient motor signals fail to capture attention immediately.

CHAPTER 6

GENERAL DISCUSSION - CONCLUSIONS

Chapters Summary & Main Findings of the Thesis

The main question of interest that the current thesis addressed, concerns the way that different types of higher level cognitive functions can aid visual perception. Semantic knowledge concerning object identity and function augments perceptual processes related to object and scene perception by guiding the deployment of eye-movements and attention as well as by using functional information about the potential interactions of objects and schemata, to manipulate encoding and retrieval of relevant information from visual memory. Therefore, my research addresses the question regarding the interaction between motor and perceptual systems, and the use of feedback from objects' functional interactions and action affordances in object recognition and prioritization.

In Chapter 1 a number of definitions for action affordances were presented. The use of the term in the current thesis was clarified as referring to the main action affordance of an object, as defined by its intended function. A series of evidence was presented regarding influences of objects' action affordances on visual perception and recognition. Moreover similar effects of functional interactions on language were discussed. Such influences were supported by a combination of evidence in favour of perceptual grouping of functionally interacting objects as well as physical affordances of objects and interactions of motor and perceptual responses. This evidence implies that the action that each object affords can be encoded automatically and in parallel with perception, but still effects of action are modulated by attention. These action influences were

argued to show similarities with other effects related to context and were connected to the question of the content and organisation of visual memory.

In Chapter 2 we tested how abstract is the nature of the perceptual grouping of objects based on their functional interaction. Specifically, we tested if manipulation of the separation of a pair of objects is in position to affect their grouping. No such effect of distance was demonstrated on perceptual grouping in Experiment 1.1, even though the same manipulation demonstrated measurable effects in the spatial description of the objects in the linguistic Experiment 1.2. Similarly with low level Gestalt findings, perceptual grouping works at a certain level of abstraction. Our finding is compatible with the finding that it is simulation of the interaction and implicit motion that connects the two objects in a perceptual entity (Riddoch, Bodley-Scott & Humphreys, 2010). Moreover this finding suggests that action affordances can influence perception in real world situations, such as when viewing real world scenes. Perceptual grouping could be achieved despite factors such as crowding or distance of the objects in a scene during our every-day operations. Finally, the difference between the perceptual (Exp 1.1) and linguistic (Exp 2.1) experiments demonstrates that action affordances operate differently, depending on the stage of visual processing of an object.

Although our results replicated the finding of the perceptual grouping of objects both semantically and functionally related, based on their configuration, a number of studies related to action affordances questioned the automatic nature of their influences. Moreover, differences related to the goal of an observer and according to whether an action was intended have different effects on perception. We needed to further test how

automatic is the influence of action affordances, and separate pre-attentive from post-perceptual effects. To do this we moved to a simpler configuration of the action affordance of an object, as compared to interaction of the affordances of a pair of objects. Also we wanted to test these influences in a more realistic context than abstract experimental designs and test whether they can be of use by the visual system in our every-day life. To do this we used a novel adaptation of the object prioritization paradigm and included eye-tracking data to measure action affordance effects at different stages of scene and object processing.

A series of experiments was designed to answer these questions, and their findings were presented in Chapter 3. This second series of experiments extended research of action affordance effects on object recognition and memory encoding in real world scenes. Experiment 2.1 demonstrated the success of our action affordance manipulation and its independence from semantic influences. Experiment 2.2 tested how action affordance violations can be used by the visual system to prioritize a critical object and bring it in the focus of attention and did not provide any evidence for influence of the action affordance manipulation in attentional prioritization, falsifying the hypothesis that automatic activations related to action affordances can be pre-attentively used during prioritization, unlike the evidence for semantic influences of prioritization (Brockmole & Henderson, 2008). Of course it cannot be claimed that activations of motor areas do not accompany the visual analysis of the object, without using relevant neuro-imaging data. Although action affordance effects could not be used pre-attentively in Experiment 2.2, Experiment 2.3 demonstrated their post-perceptual influences in attentional

prioritization (indications of the same finding were also reported in Experiment 2.2). Object orientation and functionality information is only relevant to attentional prioritization post-perceptually and not pre-attentively during object recognition.

The findings of these experiments were discussed in Chapter 4, in conjunction with the existing literature. Findings suggest that features related to object positioning and orientation are important elements of the object representation and add to the visual memory theory of scene representation (Hollingworth & Henderson, 2002) that action affordances are also part of scene memory representations. The lack of an effect of action affordance consistency after an onset in first look probabilities in the Experiment 2.2, in conjunction with baseline differences in fixation probabilities between functionally consistent and inconsistent objects, provides evidence in favour of an “attention hypothesis”, suggesting that perceptual encoding is not pre-attentively influenced by the object’s action affordance. Action affordance influences take place during the active process of building the visual representation of the scene. Moreover our findings of the modulation of attention by action affordance violations, after the object has been prioritized, are in line with evidence that eyes tend to dwell longer on semantically inconsistent as compared to consistent objects. Finally our results were further reviewed in terms of the literature related to how differential action intentions alter the information that we respond to in visual displays and the way objects are coded. It is possible that pre-attentive effects of action affordances on perception could be detected in tasks where an actual action is planned or executed.

Finally, in Chapter 5, the implications of our findings in relation to broader questions related to contextual effects, semantic influences and attention influences on the prominence of the memory encoding of an object were presented. The coding of features or objects in relation to other objects in the scene has been studied extensively in recent years. The nature of the information coded in memory seems to be at least partly relational. Based on the evidence in this thesis it is suggested that action affordance influences operate in a manner similar to semantic influences, so they constitute another kind of contextual effects, but they do not exactly belong to the same family with semantics. Motoric activations and action simulations accompany action affordance information, which links their influences to procedural knowledge, in addition to semantics. Differences between action affordances and semantics were also demonstrated in this thesis. For example, the demonstrated influences of semantic consistency of an object onset in a scene on memory guided prioritization were absent in the case of similar action affordance consistency manipulations. This evidence led to the conclusion that action affordance influences are slower than semantic influences, which could be based on fast extraction of gist information. Action affordance influences could be rather based on simulations of action (cf. Riddoch, Bodley-Scott & Humphreys, 2010) and influence perception at later stages of processing.

This thesis therefore argues against automatic and task-independent influences of action affordance activations on visual perception. Influences of action affordances on attention and the prominence of object memory representations are more important. Our eye-tracking experiments demonstrate that action affordances lead to attentional

influences, which consequently affect the object's memory encoding and favour the prominence of functionally inconsistent objects and their representations in VWM and LTM.

The role of the motor system

Before concluding this thesis it is worth expanding its findings in relation to the question of the contribution of motor systems in perception. This was one of the main questions that motivated this research, as described in Chapter 1. One of the critical points of the literature review focused on whether the input from the motor system in the perceptual system is essential for the perception of objects with specific action affordances. At an extension of this question, another critical point is at which extend motor areas provide feedback to the perceptual processes by default, in an automatic way, or whether this can only happen under certain conditions, where the activation of motor related information can be involved in the perceptual processing when needed.

This issue is a big theoretical question not resolved in its entirety by research within this thesis. There is definitely a long way to go for research to answer all these questions, but this thesis tries to pinpoint factors that are important for this question, based on the extensive reviewing of different experiments within the literature related to these questions, a number of experiments organised to break down the contributions of different components to the effects of action affordances on perception and therefore tries to provide a basis for further experimentation and research. Many different areas, such as neglect patient research, the mirror neurons literature, experiments regarding

commonalities between perception and action, theories about the two different streams of visual processing (what versus where) implicitly or explicitly pre-suppose a role of motor systems during object recognition and analysis of perceptual information.

Nevertheless, despite the increasing interest over the last few decades and the ease of speculating motor feedback on perception, there is no extensive understanding of the mechanisms of how such a feedback can be achieved and of the situations that stand as pre-requisites for this role of the motor system.

One of the problems related to the role of the motor system's feedback in the process of perception, such as for example in the case of object recognition, is causality. Even if in the cases such motor areas' involvement in perception can be demonstrated by appropriate behavioural or neurophysiological measures, it is not easy to deduct that these activations mean that the motor system plays a causal role for perception. This point will be further developed at the last part of this chapter dealing with limitations and future directions for research. What emerges from the evidence from this thesis is firstly the problem of how action affordance influences have been approached by different experimenters and the potential problem that arises when grouping them as evidence of the influence of the motor system from the very early stages of perception. Secondly, a number of factors that could be influencing findings related to influences of action affordances and object functionality in perception have been pointed out and an attempt for a first separation of the contribution of each of these factors was made, as described in the previous chapters throughout this thesis.

Based on the evidence provided by this thesis, we can even stipulate about a possible model of when and how action affordances can facilitate object perception or recognition. For example, opposite to the prediction of action affordance activations affecting prioritization, Experiment 2.2. revealed that such a possible input related to motoric activations was irrelevant, even though similar semantic consistency factors have fast pre-attentive effects on prioritization. This finding was important for the discussion of the similarities and differences between semantic and action affordance effects. It seems that action affordance effects could not have as fast effects in the specific paradigm as gist related semantic consistency effects. Therefore, action affordance effects might be creating a functionality based local context, but they don't always have fast effects from early on during the perceptual process. On the other hand various post-selection effects were reported in our experiments and action affordance information was found to affect the modulation of attentional resources and the prominence of objects' memory encoding in visual working memory.

A problem with the use of action affordances and relevant motoric information in the real world is at what extend we need hypothesize activations of the motor system related to the objects within such real world scenes. In the rich in information visual environment of the real world, there is a big number of separate objects comprising a scene, and most of these objects can allow for a number of compatible actions. This point relates back to the discussion regarding the definition of action affordances in Chapter 1, where the different definitions between various researchers were discussed. It was also mentioned that in the scope of the present thesis, the term action affordance is

used to describe the main action that the critical objects in our stimulus set is designed for. Nevertheless, objects such as the ones used in the experiments in the present thesis, which were constructed for a specific function, might have a dominant action affordance, based not only on the proximity in time and space (e.g. as in the case of the object pairs used in previous experiments as well as the experiments in Chapter 2 of this thesis), but also on the actual motor use or their actual manipulation during their interaction. It is not a coincidence for example that many of the objects used as stimuli are objects such as tools, which are man-made and designed for the execution of very specific actions. The primary action related to such objects is clearer and more usual as compared to alternative actions that can be performed with the specific object.

Nevertheless, action affordances, as defined in the present thesis, and their influences should not necessarily be attributed to the causal contribution of the motor system, as pointed out in the beginning of the previous paragraph. As noted in the literature related to semantic relationships, there is a long learning process during the experience of our interaction with the world. In Chapter 1 theories of Hebbian learning (Hebb, 1949) were mentioned, pointing out how co-occurrence in space and time can sensitize the visual system to perceptual units. Semantic units can be formed in a similar way, but, as implied by the old distinction between semantic and procedural knowledge, there is an additional element of the actual manipulation of an object that can perform a specific action. In Chapter 1 it was also mentioned how the event-related parsing of the world is determined by causal action between objects. The procedural knowledge for the actual motor programming accompanying the execution of the function of an object can also be

part of the functional schema of the object, linking the action to the semantic information about the object, forming some kind of functional semantics. Moreover, activation of such schemata might not be automatic, but it might be based on the focus of attention on action related information, due to the strong connotation of a specific action by an object such as a tool, or due to instructions or the task to be executed when perceiving the specific object.

Posner's analogy of attention as a spotlight (Posner, Snyder & Davidson, 1980) is useful in discussing this point related to the role of action affordances in modulating attention and the prominence of the representation in memory, which was analyzed throughout the current thesis. According to this theory, attention is like a spotlight which can be used to shed light towards specific objects, leading to their detailed perceptual processing. In the experiments presented in this thesis, it seems that this attentional spotlight is necessary for action affordance influences to become evident. Before the object is selected for further processing, its action affordance does not have an influence in its prioritization. Selection for further processing is necessary for the differences between objects with the correct action affordance, as compared to objects in an incorrect orientation which violates the object's primary action affordance. We can treat this selection of the critical object for further processing as the bringing of the critical object in the centre of the spotlight.

One issue that has been controversial for a while though, is the arbitrariness of the coincidence of attention with the locus of fixation during eye-movements. Although they are usually tightly coupled (Deubel & Schneider, 1996; Henderson & Ferreira, 2004;

Henderson, Pollatsek & Rayner, 1989; Shepard, Findlay & Hockey, 1986), there are also instances where the two can be independent (see for example Müller, Malinowski, Gruber & Hillyard, 2003). This issue has often been relatively ignored in eye-movements research. Both this issue of the de-coupling of attention from the locus of fixation as well as our findings regarding post-perceptual effects of action affordances can be accounted for if we approach the spotlight analogy from a different angle. Instead of hypothesizing a single spotlight that represents that attention is directed towards a specific object, we can think of attention as a variety of many smaller spotlights. This way the analogy can quantify and account for differences of the attentional resources allocated to a specific object; what is important is how these resources will be allocated. The more of the available spotlights are directed towards the critical object, the better the encoding of a critical object in visual memory will be.

In Experiment 2.3 for example, the differences of the memory encoding of objects that violate the functional schema of their correct orientation were found to be based on attracting more and longer fixations before the critical orientation change. In other words, larger attentional resources were assigned in the case of incorrectly oriented objects. More importantly, faster prioritization of their orientation change, as compared to correctly oriented objects, was reported. Also, as described in previous chapters, there were not only baseline differences in fixations number and durations between correctly and incorrectly oriented objects, but also differential lingering of attention, with longer disengagement time from incorrectly oriented objects. With the analogy of many small spotlights, we can describe object perception during scene viewing as the gradual

inspection of the content of the scene, with most of the attentional spotlights focusing on the objects within it in synchrony during each fixation and moving serially from object to object. For the purpose of this description I ignore the first part of gist extraction and holistic processing and I focus at the process of object perception, which comes after the initial stage of holistic scene perception (e.g. Potter, 1976; Schyns & Oliva, 1994; Oliva, Torralba, Castelhana & Henderson, 2003; Torralba & Oliva, 2003).

After an object that has a specific action affordance is selected for further processing (the first time that it is fixated within the scene) a number of these attentional spotlights are directed on it to encode it in visual memory and add the object and its critical features in the memory representation of the scene. Consequently, some of these spotlights might remain on the critical object in the case of a functional violation, e.g. an incorrect orientation incompatible with its action affordance. This represents a kind of residual attentional resources, which could be used to tag the inconsistency from the action affordance schema. As a consequence, when there is an unexpected orientation change, attention can be more readily directed back to the object that violated the relevant action affordance schema, after its unexpected orientation change. In other words the orientation change triggers the allocation of most of the attentional resources (spotlights) back to the critical object of interest.

This analogy accounts for the faster prioritization of initially incorrectly oriented objects after an orientation change. It is also compatible with the object file theory, in the sense that an amount of the attentional resources can be devoted to this readiness to detect the change of the critical feature of the object; in this case orientation related

information is more important for the object file in the case of incorrectly oriented rather than correctly oriented objects. In other words, orientation affects the prominence of the encoding of the specific feature and in extension the encoding of the whole object in memory. This point also relates to the discussion in the previous chapters about the importance of directing attention to action-relevant features, in the experiments in literature that report behavioural influences of action affordances.

As a conclusion, according to this model, not all action relevant information is automatically activated with respect to every object in our visual field, as this would require a huge amount of attentional and other higher level resources, and the gain would be uncertain. Unlike semantic information, where the extraction of the gist of a scene can help the decision of where the initial eye movements should be directed, functional semantics and the relevant procedural and motor representations could be useful at a slightly later stage of perception, related to object based perception and the parsing of the scene to objects of interest. When an object is fixated for further processing and representation within the scene memory encoding, action affordance related information can be used under certain conditions.

Such information could be evolutionary useful when preparing an action related to the perceived object or a reaction to an unexpected change, as in case described in the Chapter 3 (page 126), where the intention to grasp a cup must be quickly adjusted when accidentally hitting the cup with the result of it dropping on the table, or even off the table. This means that the orientation of its functional part (the handle) was unexpectedly changed and the motor program of grasping must be changed accordingly.

The comparative analysis of the literature review in Chapter 1 shows that an actual execution of an action is not necessarily a prerequisite for such feedback of functionality related information on object perception, but there may be many factors that trigger the contribution of such information on perception, such as the task to be executed, the instructions in an experimental setting or the indirect focus of attention in the functional parts of an object. This is the reason why it is claimed that the context set by the task can modulate how action affordance related information will (or will not) be used.

Limitations & Future directions of the present thesis

Limitations. Some of the limitations of the experiments presented in the current thesis were mentioned at various points throughout this thesis. In Chapter 1 the definition of action affordances within the thesis was presented, pointing out that some of the effects reported in the action affordance literature can be accounted for by a combination of motoric activations and more generic procedural knowledge, and the two cannot be easily differentiated “a posteriori”. The methodological approach in the current thesis did not utilise any means of monitoring the activation of motor areas during the perception of objects with different action affordances, such as neuroimaging, nor did it control for the contribution of such areas (e.g. by TMS).

In the previous section, the limitations imposed by the methodology of our experiments were also pointed out, with regard to the involvement of the motor system during perception. It was argued that even if we can quantify the involvement of motor areas of the brain during the perception of action affordances or interactions between

objects through the use of functional neuroimaging, there would be an additional problem of establishing the causality of the relationship between the activated brain areas and the behavioural measures of object perception assigned to action affordances. This relationship might be correlational and assigning causality in one over the other would not be correct. Moreover, activation of motor areas might relate to the execution of the response required by the task used (e.g. a button press) or the execution of an eye-movement. In this sense, direct involvement with the degree of contribution from motor areas during the early perceptual stages could allow for the manipulation aspect required, for the experimenter to set up an appropriate experiment. Such experimental control could be achieved by “activation” or “blocking” of related motor areas of the brain through the use of TMS. This way the experimenter could make conclusions about the causal role of motor systems in perception, and help answer questions such as if relevant motoric activations are both adequate and necessary in explaining the findings related to action affordances, object functionality and perceptual grouping of objects that form a functional pair.

Finally, there are a number of questions regarding the grouping of different kinds of findings regarding effects of action affordances, as described in the current thesis. The experimental approach of the interaction between perception and action is relatively recent, as demonstrated in the discussion about the shift of paradigm from models where action is presented as the output of a serial perceptual process towards parallel analysis of perceptual and motor activations. A number of advances in technology have allowed experimenters to measure more subtle influences of action affordances, compared to the

measures traditionally used, such as Reaction Times. Nevertheless, there are a number of issues analyzed throughout this thesis, that the current experiments were not designed to answer.

It was already mentioned that there might be differences in the findings of experiments related to the execution of an actual movement or experiments where the context of the task adds relevance to the accompanying motoric activations. In our experiments, there was no intention to perform a real movement. In the experiments presented in Chapter 3, the perception of the critical object was not even instructed by the task; we took advantage of the fact that the critical object will be prioritized anyway during an onset or orientation change. Although such choices were justified by our intention to test action affordance effects in their simplest form and to avoid task-induced priming of action affordances, such effects could nevertheless be stronger in cases of execution or at least intention to execute an action.

Also, there might be a qualitative difference between how action affordances are treated by the visual system in the experiments in Chapter 2 as compared to the ones in Chapter 3. In the case of the eye-tracking experiments in Chapter 3 action affordances of a single object were defined as the main function that is associated with the specific object and describe its interaction with an agent manipulating it. In other words the action affordance relates to the interaction of the observer, who could be potentially performing the appropriate action, and the object. Whereas in the case of pairs of objects, as used in experiments in Chapter 2, the action affordance relates both to the relationship of the observer as a potential agent manipulating each of the two objects,

but also in the relationship between the combined use of the two objects. In other words the action affordance influences in such functionally related pairs of objects might be something more than the sum of the action affordance influences of each of the two objects in relation to the observer. Moreover, due to the methodology used, the series of experiments for the current thesis are not in position to add any insight to the neural substrates that support our findings related the similarities and differences between semantic and action affordances.

Future directions. There are a number of issues when trying to model the relationship between perceptual and motor systems, but hopefully research focusing on this area will be in position to answer related questions by strict definition of the terminology used and excessive care in taking into account the confounds of uncontrolled factors when proceeding with conclusions. As in many areas in psychology, neuroimaging can provide us with a useful resource of a rich body of information, but it is not adequate on its own to solve the core issues regarding the interaction of perception and action. What is primarily needed is a coherent theory as a broad reference frame and suitably designed experiments, which will extract the right answers by asking the right questions.

Given the experiments presented in the current thesis, I think that future research should move towards the directions implied by their key findings. It would be worth to further explore the nature of action affordance effects and object interactions in comparison with semantic consistency. The fact that they operate in a manner similar to semantics, as indicated by the similarity of semantic and action affordance effects,

indicates that action affordance information can be used by the visual system in a way similar to other semantic effects. The differences though might indicate that there are additional factors, possibly related to procedural information or the involvement of the motor system, which differentiates action affordance from semantic influences.

Moreover, action affordance influences, as described in the current thesis, were found to be important at later perceptual stages as compared to semantic effects based on gist.

Further comparison between semantic and action affordance effects would be in position to provide evidence related to the process of object based perception.

Moreover, future experiments should move towards the direction of comparing action affordance effects in cases where an action is to be executed and when no actual action is involved, under the same experimental paradigm. This way, not only would motor influences be stronger in the case of an intention to act, but it could also be tested whether motor activations are related to the effects of action affordances reported within the present thesis. In other words, if the contribution of the motor system is related to such action affordance effects, we could expect greater action affordance influences in the presence of an action. Appropriate neuroimaging techniques, such as fMRI, MEG or EEG could be combined with such experiments to measure the contribution of areas of the brain involved in the preparation or execution of a motor response. The use of Event Related Potentials can also provide more information regarding how early in the processing of an object in a scene, action affordance information can be used. Finally, to probe whether such motor system involvement plays a causal role in the perception of objects with a specific functionality, methods like TMS could be used to neutralise

targeted areas of the brain and check how this would influence the reported facilitation of the perceptual grouping of functionally related objects or action affordance inconsistencies.

Finally, it would be useful to test the findings on neglect patients, to further explore the role of attention in the memory encoding of objects and their contribution in the action affordance effects reported within the current thesis. Research in clinical populations such as neglect patients and the role of action affordances in modulating the phenomenon of extinction initially led to the exploration of perceptual-motor interactions. The object prioritization paradigm could be used in patients in a similar way to the healthy volunteers used in the experiments reported within this thesis to compare how prioritization will be affected by attentional limitations, and compare action affordance effects between the neglected and the unaffected visual field. Conducting similar eye-tracking experiments on such a patient group can provide a way of determining the influence of attentional resources on these action affordance influences.

References

- Adelson, E. H. (1993). Perceptual Organization and the Judgement of Brightness. *Science*, 262, 2042-2044.
- Adelson, E. H. (2000). Lightness Perception and Lightness Illusions. In M. Gazzaniga (Ed.), *The New Cognitive Neurosciences* (Vol. 2nd, pp. 339-351). Cambridge, MA: MIT Press.
- Aguirre, G. K., Zarahn, E., & D'Esposito, M. (1998). Neural components of topographical representation. *Proceedings of the National Academy of Sciences, USA*, 95, 839-846.
- Allport, A. (1987). Selection for action: Some behavioral and neurophysiological considerations of attention and action. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 395-419). Hillsdale, NJ: Erlbaum.
- Alvarez, G. A., & Oliva, A. (1998). The Representation of Simple Ensemble Visual Features Outside the Focus of Attention. *Psychological Science*, 19(4), 392-398.
- Antes, J. R. (1974). The time course of picture viewing. *Journal of Experimental Psychology*, 103, 62-70.
- Ariely, D. (2001). Seeing sets: Representation by statistical properties. *Psychological Science*, 12, 157-162.
- Ariely, D. (2001). Seeing sets: Representation by statistical properties. *Psychological Science*, 12(2), 157- 162.
- Ariely, D., & Burbeck, C. A. (1995). Statistical encoding of multiple stimuli: a theory of distributed representation. *Investigative Ophthalmology and Visual Science*, 36(Suppl.), 8472 (Abstract).
- Assmus, A., Giessing, C., Weiss, P. H., & Fink, G. R. (2007). Functional interactions during the retrieval of conceptual action knowledge: An fMRI study. *Journal of Cognitive Neuroscience*, 19, 1004-1012.
- Auckland, M., Cave, K. R., & Donnelly, N. (2004). Perceptual errors in object recognition are reduced by the presence of context objects [Abstract]. *Abstracts of the Psychonomic Society*, 8, 109.
- Averbach, E., & Coriell, A. S. (1961). Short-term memory in vision. *The Bell System Technical Journal*, 40, 309-328.
- Bar, M., & Ullman, S. (1996). Spatial context in recognition. *Perception*, 25, 343-352.
- Barchilon Ben-Av, M., Sagi, D., & Braun, J. (1992). Visual attention and perceptual grouping. *Perception & Psychophysics*, 52, 277-294.

- Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, 22, 577-660.
- Baylis, G. C., Driver, J., & Rafal, R. D. (1993). Visual extinction and stimulus repetition. *Journal of Cognitive Neuroscience*, 5(4), 453-466.
- Beck, J. (1969). Lightness and orientation. *The American Journal of Psychology*, 82(3), 359-366.
- Bekkering, H., & Neggers, S. F. W. (2002). Visual search is modulated by action intentions. *Psychological Science*, 13(4), 370-374.
- Belopolsky, A., Theeuwes, J., & Kramer, A. F. (2005). Prioritization by transients in visual search. *Psychonomic Bulletin & Review*, 12, 93-99.
- Berbaum, K., Bever, T., & Chung, C. S. (1984). Extending the perception of shape from known to unknown shading. *Perception*, 13, 479-488.
- Berbaum, K., Bever, T., & Chung, C. S. (1984). Extending the perception of shape from known to unknown shading. *Perception*, 13, 479-488.
- Beun, R. J., & Cremers, A. H. M. (1998). Object reference in a shared domain of conversation. *Pragmatics & Cognition*, 6, 121-152.
- Biederman, I. (1972). Perceiving real-world scenes. *Science*, 177, 77-80.
- Biederman, I. (1981). On the semantics of a glance at a scene. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 213-263). Hillsdale, NJ: Erlbaum.
- Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, 94, 115-147.
- Biederman, I., Bickle, T. W., Teitelbaum, R. C., & Klatsky, G. J. (1988). Object search in non-scene displays. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 14, 456-467.
- Biederman, I., & Cooper, E. E. (1991). Priming contour-deleted images: Evidence for intermediate representations in visual object recognition. *Cognitive Psychology*, 23, 393-419.
- Biederman, I., Mezzanotte, R. J., & Ravinowitz, J. C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology*, 14, 143-177.
- Biederman, I., Rabinowitz, J. C., Glass, A. L., & Stacy, E. W. (1974). On the information extracted from a glance of a scene. *Journal of Experimental Psychology: General*, 103, 597-600.
- Boot, W. R., Kramer, A. F., & Peterson, M. S. (2005). Oculomotor consequences of abrupt object onsets and offsets: Onsets dominate oculomotor capture. *Perception & Psychophysics*, 67, 910-928.

- Boyce, S. J., & Pollatsek, A. (1992). Identification of objects in scenes: The role of scene background in object naming. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 18, 531-543.
- Boyce, S. J., Pollatsek, A., & Rayner, K. (1989). Effect of background information on object identification. *Journal of Experimental Psychology: Human Perception & Performance*, 15, 556-566.
- Brady, T., & Chun, M. M. (2007). Spatial constraints on learning in visual search: modeling contextual cuing. *Journal of Experimental Psychology: Human Perception & Performance*, 33, 798-815.
- Brewer, W. F., & Treyens, J. C. (1981). Role of schemata in memory for places. *Cognitive Psychology*, 13, 207-230.
- Broadbent, D. E. (1958). *Perception and Communication*. New York: Pergamon Press.
- Brockmole, J. R., Castelhana, M., & Henderson, J. M. (2006). Contextual Cueing in Naturalistic Scenes: Global and Local Contexts. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 32(4), 699-706.
- Brockmole, J. R., & Henderson, J. M. (2005a). Prioritization of New Objects in Real-World Scenes: Evidence From Eye Movements. *Journal of Experimental Psychology: Human Perception & Performance*, 31, 857-868.
- Brockmole, J. R., & Henderson, J. M. (2005b). Object appearance, disappearance and attention prioritization in real world-scenes. *Psychonomic Bulletin & Review*, 12(6), 1061-1067.
- Brockmole, J. R., & Henderson, J. M. (2006). Using real-world scenes as contextual cues for search. *Visual Cognition*, 13(1), 99-108.
- Brockmole, J. R., & Henderson, J. M. (2008). Prioritizing new objects for eye fixation in real-world scenes: Effects of object-scene consistency. *Visual Cognition*, 16(2/3), 375-390.
- Brockmole, J. R., Wang, R. F., & Irwin, D. E. (2002). Temporal integration between visual images and visual percepts. *Journal of Experimental Psychology: Human Perception & Performance*, 28, 315-334.
- Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, 97, 523-547.
- Burgess, N., Maguire, E. A., & O'Keefe, J. (2002). The human hippocampus and spatial and episodic memory. *Neuron*, 35, 625-641.
- Buswell, G. T. (1935). *How people look at pictures*. Chicago: The University of Chicago Press.
- Carlson, L. A., & Covey, E. S. (2005). How far is *near*? Inferring distance from spatial descriptions. *Language and Cognitive Processes*, 20(5), 617-631.

- Carlson, L. A., & Kenny, R. (2006). Interpreting spatial terms involves simulating interactions. *Psychonomic Bulletin & Review*, 13(4), 682-688.
- Carlson, L. A., & van Deman, S. R. (2004). The space in spatial language. *Journal of Memory & Language*, 51, 418-436.
- Carlson-Radvansky, L. A. (1999). Memory for structural information across eye movements. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 21, 1441-1458.
- Carlson-Radvansky, L. A., Covey, E. S., & Lattanzi, K. M. (1999). "What" effects on "Where": Functional Influences on Spatial Relations. *Psychological Science*, 10(6), 516-521.
- Carlson-Radvansky, L. A., & Irwin, D. E. (1994). Reference frame activation during spatial term assignment. *Journal of Memory & Language*, 33, 646-671.
- Carlson-Radvansky, L. A., & Irwin, D. E. (1995). Memory for structural information across eye-movements *Journal of Experimental Psychology: Learning, Memory & Cognition*, 21, 1441-1458.
- Carlson-Radvansky, L. A., & Logan, G. D. (1997). The influence of reference frame selection on spatial template construction. *Journal of Memory & Language*, 37, 411-437.
- Carlson-Radvansky, L. A., & Radvansky, G. A. (1996). The influence of functional relations on spatial term selection. *Psychological Science*, 7(1), 56-60.
- Carlson-Radvansky, L. A., & Tang, Z. (2000). Functional influences on orienting a reference frame. *Memory & Cognition*, 28(5), 812-820.
- Cave, K. R., & Wolfe, J. M. (1990). Modelling the role of parallel processing in visual search. *Cognitive Psychology*, 22, 225-271.
- Chambers, G. C., Tanenhaus, K. M., Eberhard, H., Filip, G. N., & Carlson, G. N. (2002). Circumscribing referential domains during real time language comprehension. *Journal of Memory & Language*, 47, 30-49.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *Neuroimage*, 12, 478-484.
- Chong, S. C., & Treisman, A. (2003). Representation of statistical properties. *Vision research*, 43(4), 393-404.
- Chong, S. C., & Treisman, A. (2005a). Attentional spread in the statistical processing of visual displays. *Perception & Psychophysics*, 67, 1-13.
- Chong, S. C., & Treisman, A. (2005b). Statistical processing: computing the average size in perceptual groups. *Vision Research*, 45, 891-900.
- Chun, M. M. (2003). Scene perception and memory. *Psychology of Learning and Motivation*, 42, 79-108.

- Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology*, 36(1), 28-71.
- Chun, M. M., & Jiang, Y. (1999). Top-down attentional guidance based on implicit learning of visual covariation. *Psychological Science*, 10, 360-365.
- Chun, M. M., & Phelps, E. A. (1999). Memory deficits for implicit contextual information in amnesic patients with hippocampal damage. *Nature Neuroscience*, 2, 844-847.
- Cohen, J. D., & Huston, T. A. (1994). Progress in the use of interactive models for understanding attention and performance. In T. Inui & J. L. McClelland (Eds.), *Attention and performance* (Vol. XV, pp. 453-476). Cambridge, MA: MIT Press.
- Conci, M., Böbel, E., Matthias, E., Keller, I., Müller, H. J., & Finke, K. (2009). Preattentive surface and contour grouping in kaniza figures: Evidence from parietal extinction. *Neuropsychologia*, 47, 726-732.
- Context effect. (2010). Encyclopædia Britannica. Retrieved July 08, 2010, from Encyclopædia Britannica Online: <http://www.britannica.com/EBchecked/topic/134777/context-effect>
- Coventry, K. R., & Garrod, S. C. (2004). *Saying, seeing and acting: The psychological semantics of spatial prepositions*. Hove, UK: Psychology Press.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. (1999). Action for perception: a motor-visual attentional effect. *Journal of Experimental Psychology: Human Perception & Performance*, 25, 1673-1692.
- Critchley, M. (1953). *The parietal lobes*. London: Hafner Press.
- Currie, C., McConkie, G., Carlson-Radvansky, L. A., & Irwin, D. E. (2000). The role of the saccade target object in the perception of a visually stable world. *Perception & Psychophysics*, 62, 673-683.
- Currie, C. B., McConkie, G. W., Carlson-Radvansky, L. A., & Irwin, D. E. (2000). The role of the saccade target object in the perception of a visually stable world. *Perception & Psychophysics*, 62, 673-683.
- Davenport, J. L. (2007). Consistency effects between objects in scenes. *Memory & Cognition*, 35, 393-401.
- Davenport, J. L., & Potter, M. C. (2004). Scene consistency in object and background perception. *Psychological Science*, 15, 559-564.
- de Graef, P., Christiaens, D., & d' Ywalle, G. (1990). Perceptual effect of scene context on object identification. *Psychological Research*, 52, 317-329.
- De Schepper, B., & Treisman, A. (1996). Visual memory for novel shapes: Implicit coding without attention. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 22, 27-47.

- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18, 193-222.
- Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, 36, 1827-1837.
- Deubel, H., Schneider, W. X., & Paprotta, I. (1998). Selective dorsal and ventral processing: Evidence for a common attentional mechanism in reading and perception. *Visual Cognition*, 5, 81-107.
- DeYoe, E., & van Essen, D. C. (1988). Concurrent processing streams in monkey visual cortex. *Trends in Neuroscience*, 11, 219-226.
- Di Lollo, V. (1980). Temporal integration in visual memory. *Journal of Experimental Psychology: General*, 109, 75-97.
- di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research*, 91, 176-180.
- Diamond, A. (1990). Developmental time course in human infants and infant monkeys, and the neural bases of inhibitory control in reaching. *Annals of the New York Academy of Sciences*, 608, 637-676.
- Diwadkar, V. A., & McNamara, T. P. (1997). Viewpoint dependence in scene recognition. *Psychological Science*, 8, 302-307.
- Donk, M., & Theeuwes, J. (2003). Prioritizing selection of new elements: Bottom-up versus top-down control. *Perception & Psychophysics*, 65(1231-42).
- Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, 113, 501-517.
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, 96(3), 433-458.
- Duncan, J., Humphreys, G. W., & Ward, R. (1997). Competitive brain activity in visual attention. *Current Opinion in Neurobiology*, 7, 255-261.
- Eckstein, M. P., Drescher, B. A., & Shimozaki, S. S. (2006). Attentional cues in real scenes, saccadic targeting, and Bayesian priors. *Psychological Science*, 17(11), 973-980.
- Egley, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General*, 123, 161-177.
- Ellis, R., & Tucker, M. (2000). Micro-affordance: the potentiation of components of action by seen objects. *British Journal of Psychology*, 9, 451-471.

- Enns, J. T., & Rensink, R. A. (1990). Influence of scene-based properties on visual search. *Science*, 247, 721-723.
- Epstein, R., & Kanwisher, N. (1998). A cortical representation of the local visual environment. *Nature*, 392, 598-601.
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception and Psychophysics*, 16, 143-149.
- Eriksen, C. W., & Yeh, Y.-Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Learning & Memory*, 11, 583-597.
- Ettlinger, G. (1990). "Object vision" and "spatial vision": the neuropsychological evidence for the distinction. *Cortex*, 26 (3), 319-341.
- Farah, M. J., Wallace, M. A., & Vecera, S. P. (1993). "What" and "Where" in visual attention: Evidence from the neglect syndrome. In I. Robertson & J. C. Marshall (Eds.), *Unilateral neglect: Clinical and experimental studies*. Hove, UK: Lawrence Erlbaum Associates Ltd.
- Farivar, R. (2009). Dorsal-ventral integration in object recognition. *Brain Research Reviews*, 61(2), 144-153.
- Fischer, M. H., & Hoellen, N. (2004). Space- and object-based attention depend on motor intention. *The Journal of General Psychology of Learning & Motivation*, 131, 365-378.
- Friedman, A. (1979). Framing pictures: The role of knowledge in automatized encoding and memory for gist. *Journal of Experimental Psychology: General*, 108, 316-355.
- Friedman, A., & Liebelt, L. S. (1981). On the time course of viewing pictures with a view towards remembering. In D. F. Fisher, R. A. Monty & J. W. Senders (Eds.), *Eye movements: Cognition and visual perception* (pp. 137-155). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, 119, 593-609.
- Gallistel, C. R. (1990). *The organisation of learning*. Cambridge, MA: MIT Press.
- Gapp, K. P. (1995). Angle, distance, shape and their relationship to projective relations. In J. D. Moore & J. F. Lehman (Eds.), *Proceedings of the 17th Annual Conference of the Cognitive Science Society* (pp. 112-117). Mahwah, NJ: Cognitive Science Society.
- Garnham, A. (1989). A unified theory of meaning of some spatial relational terms. *Cognition*, 31, 45-60.
- Gerlach, C., Law, I., Gade, A., & Paulson, O. B. (2002). The role of action knowledge in the comprehension of artefacts - a PET study. *Neuroimage* 15(1), 143-152.

- Gibson, B. S. (1996). Visual quality and attentional capture: A challenge to the special role of abrupt onsets. *Journal of Experimental Psychology: Human Perception & Performance*, 22, 1496-1504.
- Gibson, J. J. (1950). *The perception of the visual world*. Boston, MA: Houghton Mifflin.
- Gibson, J. J. (1977). The Theory of Affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, Acting, and Knowing*: Lawrence Erlbaum Associates.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston MA: Houghton Mifflin.
- Gilchrist, A. (2006). *Seeing black and white*. Oxford: Oxford University Press.
- Gilchrist, I. D., Humphreys, G. W., & Riddoch, M. J. (1996). Grouping and Extinction: Evidence for Low-level Modulation of Visual Selection. *Cognitive Neuropsychology*, 13(8), 1223-1249.
- Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, 9, 558-565.
- Glenberg, A. M., & Robertson, D. A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory & Language*, 43(3), 379-401.
- Goodale, M. A., Milner, A. D., Jakobson, L. S., & Carey, D. P. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature*, 349, 154-156.
- Gordon, R. D. (2004). Attentional allocation during the perception of scenes. *Journal of Experimental Psychology: Human Perception & Performance*, 30, 760-777.
- Grafton, S. T., Fadiga, L., Arbib, M. A., & Rizzolatti, G. (1997). Premotor cortex activation during observation and naming of familiar tools. *Neuroimage* 6, 231-236.
- Green, C., & Hummel, J. E. (2004). Relational perception and cognition: Implications for cognitive architecture and the perceptual-cognitive interface. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 44, pp. 201-226). San Diego, CA: Academic Press.
- Green, C., & Hummel, J. E. (2006). Familiar Interacting Object Pairs Are Perceptually Grouped. *Journal of Experimental Psychology: Human Perception & Performance*, 32(5), 1107-1119.
- Greenwald, A. (1970). Sensory feedback mechanisms in performance control: With special reference to the ideomotor mechanism. *Psychological Review*, 77, 73-99.
- Gregory, R. L. (1993). Seeing and thinking. *Giornale Italiano di Psicologia*, 20(5), 749-769.

- Grèzes, J., & Decety, J. (2002). Does visual perception of object afford action? Evidence from a neuroimaging study. *Neuropsychologia*, 40, 212-222.
- Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: an fMRI study of implicit processing. *European Journal of Neuroscience*, 17, 2735-2740.
- Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. A. Akins (Ed.), *Perception* (pp. 89-110). New York: Oxford University Press.
- Harman, K. L., Humphrey, G. K., & Goodale, M. A. (1999). Active manual control of object views facilitates visual recognition. *Current Biology*, 9, 1315-1318.
- Hayhoe, M. M., & Ballard, D. (2005). Eye movements in natural behaviour. *Trends in Cognitive Sciences*, 9(4), 188-193.
- Hayhoe, M. M., Droll, J., & Mennie, N. (2007). Learning where to look. In R. P. G. Van Gompel, M. H. Fischer, W. S. Murray & R. L. Hill (Eds.), *Eye movements: A window on mind and brain* (pp. 641-660). Oxford, UK: Elsevier.
- Hayhoe, M. M., Shrivastana, A., Mruczek, R., & Pelz, J. B. (2003). Visual memory and motor planning in a natural task. *Journal of Vision*, 3, 49-63.
- Hebb, D. O. (1949). *The Organisation of Behavior*. New York: Wiley.
- Helmholtz, H. v. (1867/1910/1962). *Treatise on physiological optics*, (Translated from the 3rd German edition, English edition 1962 ed. Vol. III). Dover.
- Henderson, J. M. (1992). Object identification in context: The visual processing of natural scenes [Special issue]. *Canadian Journal of Psychology*, 46(3), 319-341.
- Henderson, J. M. (1994). Two representational systems in dynamic visual identification. *Journal of Experimental Psychology: General*, 123, 410-426.
- Henderson, J. M. (1997). Transsaccadic memory and integration during real-world object perception. *Psychological Science*, 8, 51-55.
- Henderson, J. M. (2003). Human gaze control in real-world scene perception. *Trends in Cognitive Sciences*, 7, 498-504.
- Henderson, J. M., Brockmole, J. R., Castelano, M. S., & Mack, M. (2007). Visual saliency does not account for eye movements during search in real-world scenes. In R. v. Gompel, M. Fischer, W. Murray & R. Hill (Eds.), *Eye movements: A window on mind and brain* (pp. 537-562). Oxford: Elsevier.
- Henderson, J. M., & Ferreira, F. (2004). *The interface of language, vision, and action: Eye movements and the visual world*. New York: Psychology Press.
- Henderson, J. M., & Hollingworth, A. (1998a). Eye Movements during Scene Viewing: An Overview. In G. Underwood (Ed.), *Eye Guidance while Reading and While Watching Dynamic Scenes* (pp. 269-293). Oxford: Elsevier.

- Henderson, J. M., & Hollingworth, A. (1999a). High-level scene perception. *Annual Review of Psychology*, 50, 243-271.
- Henderson, J. M., & Hollingworth, A. (1999b). The role of fixation position in detecting scene changes across saccades. *Psychological Science*, 5, 438-443.
- Henderson, J. M., & Hollingworth, A. (2003a). Eye movements and visual memory: Detecting changes to saccade targets in scenes. *Perception & Psychophysics*, 65(1), 58-71.
- Henderson, J. M., & Hollingworth, A. (2003c). Global transsaccadic change blindness during scene perception. *Psychological Science*, 14(5), 493-497.
- Henderson, J. M., & Siefert, A. B. C. (1999). The influence of enantiomorphic transformation on transsaccadic object integration. *Journal of Experimental Psychology: Human Perception & Performance*, 25, 243-255.
- Henderson, J. M., & Siefert, A. B. C. (2001). Types and tokens in transsaccadic object identification: Effects of spatial position and left-right orientation. *Psychonomic Bulletin & Review*, 8, 753-760.
- Henderson, J. M., Weeks, P. A., & Hollingworth, A. (1999). Effects of semantic consistency on eye movements during scene viewing. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 210-228.
- Herskovits, A. (1986). *Language and spatial cognition. An interdisciplinary study of the prepositions of English*. Cambridge, England: Cambridge University Press.
- Herskovits, A. (1998). Schematization. In P. Olivier & K. P. Gapp (Eds.), *Representation and processing of spatial expressions* (pp. 149-162). Mahwah, NJ: Erlbaum.
- Hochberg, J. E. (1978). *Perception*. Englewood Cliffs, NJ: Prentice Hall.
- Hock, H. S., Gordon, G. P., & Whitehurst, R. (1974). Context effects: The influence of familiarity of arrangement, physical plausibility, and belongingness. *Perception & Psychophysics*, 16, 4-8.
- Hock, H. S., & Schmelzkopf, K. F. (1980). The abstraction of schematic representations from photographs of real-world scenes. *Memory & Cognition*, 8(6), 543-554.
- Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics*, 57, 787-795.
- Hoiem, D., Efros, A. A., & Herbert, M. (2008). Putting Objects in Perspective. *International Journal of Computer Vision*, 80, 3-15.
- Hollingworth, A. (2003). Failures of Retrieval and Comparison Constrain Change Detection in Natural Scenes. *Journal of Experimental Psychology: Human Perception & Performance*, 29(2), 388-403.

- Hollingworth, A. (2004). Constructing visual representations of natural scenes: The roles of short- and long-term visual memory. *Journal of Experimental Psychology: Human Perception & Performance*, 30, 519-537.
- Hollingworth, A. (2005). Memory for object position in natural scenes. *Visual Cognition*, 12, 1003-1016.
- Hollingworth, A. (2006). Scene and position specificity in visual memory for objects. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 32, 58-69.
- Hollingworth, A. (2009). Memory for real-world scenes. In J. Brockmole (Ed.), *The Visual World in Memory*. Sussex: Psychology Press.
- Hollingworth, A., & Henderson, J. M. (1998). Does consistent scene context facilitate object perception? *Journal of Experimental Psychology: General*, 127, 398-415.
- Hollingworth, A., & Henderson, J. M. (2000). Semantic informativeness mediates the detection of changes in natural scenes. *Visual Cognition*, 7, 213-235.
- Hollingworth, A., & Henderson, J. M. (2002). Accurate visual memory for previously attended objects in natural scenes. *Journal of Experimental Psychology: Human Perception & Performance*, 28, 113-136.
- Hollingworth, A., & Henderson, J. M. (2003). Testing a conceptual locus for the inconsistent object change detection advantage in real-world scenes. *Memory & Cognition*, 31, 930-940.
- Hollingworth, A., Schrock, G., & Henderson, J. M. (2001). Change detection in the flicker paradigm: The role of fixation position within the scene. *Memory & Cognition*, 29, 296-304.
- Hommel, B., & Colzato, L. S. (2009). When an object is more than binding of its features: Evidence for two mechanisms of visual feature integration. *Visual Cognition*, 17(1/2), 120-140.
- Hommel, B., & Elsner, B. (2009). Acquisition, representation, and control of action. In E. Morsella, J. A. Bargh & P. M. Gollwitzer (Eds.), *Oxford handbook of human action* (pp. 371-398). New York: Oxford University Press.
- Houghton, G., & Tipper, S. P. (1999). Attention and the control of action: An investigation of the effects of selection on population coding of hand and eye movement. In D. Heinke, G. W. Humphreys & A. Olson (Eds.), *Connectionist Models in Cognitive Neuroscience* (pp. 283-298). London: Springer-Verlag.
- Houghton, G. S., Tipper, P., Weaver, B., & Shore, D. I. (1996). Inhibition and interference in selective attention: Some tests of a neural network model. *Visual Cognition*, 3, 119-164.

- Hummel, J. E., & Biederman, I. (1992). Dynamic binding in a neural network for shape recognition. *Psychological Review*, 99, 480-517.
- Hummel, J. E., & Stankiewicz, B. J. (1996). Categorical relations in shape perception. *Spatial Vision*, 10, 201-236.
- Humphreys, G. W. (1989). *Parallel distributed processing and psychology*. Oxford: Blackwells.
- Humphreys, G. W. (1998). Neural representation of objects in space: A dual coding account. *Philosophical Transactions of the Royal Society of London, Series B*, 353, 1341-1352.
- Humphreys, G. W., & Riddoch, M. J. (1993). Interactions between object and space systems revealed through neuropsychology. In D. E. Meyer & S. Kornblum (Eds.), *Attention and Performance XIV* (pp. 143-162). Hillsdale, NJ: Lawrence Erlbaum.
- Humphreys, G. W., & Riddoch, M. J. (2001). Detection by action: Neuropsychological evidence for action-defined templates in search. *Nature Neuroscience*, 4, 84-88.
- Humphreys, G. W., & Riddoch, M. J. (2003). FROM WHAT TO WHERE: Neuropsychological Evidence for Implicit Interactions Between Object- and Space-Based Attention. *Psychological Science*, 14(5), 487-492.
- Humphreys, G. W., & Riddoch, M. J. (2007). How to Define an Object: Evidence from the Effects of Action on Perception and Attention. *Mind & Language*, 22(5), 534-547.
- Humphreys, G. W., Riddoch, M. J., Forti, S., & Ackroyd, K. (2004). Action influences spatial perception: Neuropsychological evidence. *Visual Cognition*, 11, 401-427.
- Humphreys, G. W., Riddoch, M. J., Linnell, K. J., Punt, D., Edwards, M. G., & Wing, A. M. (2005). Attending to what you are doing: Neuropsychological and experimental evidence for interactions between perception and action. In G. W. Humphreys & M. J. Riddoch (Eds.), *Attention in Action: Advances from Cognitive Neuroscience* (pp. 3-25). London: Psychology Press.
- Humphreys, G. W., Romani, C., Olson, A., Riddoch, M. J., & Duncan, J. (1994). Non-spatial extinction following lesions of the parietal lobe in humans. *Nature*, 372, 357-359.
- Intraub, H. (1984). Conceptual masking: The effects of subsequent visual events on memory for pictures. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 10, 115-125.
- Intraub, H. (1997). The representation of visual scenes. *Trends in Cognitive Sciences*, 1, 217-222.

- Irwin, D. E. (1991). Information integration across saccadic eye movements. *Cognitive Psychology*, 23, 420-456.
- Irwin, D. E. (1992). Visual memory within and across fixations. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp. 146-165). New York: Springer-Verlag.
- Irwin, D. E. (1992a). Memory for position and identity across eye movements. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 18, 307-317.
- Irwin, D. E., & Andrews, R. (1996). Integration and accumulation of information across saccadic eye movements. In T. Inui & J. L. McClelland (Eds.), *Attention and performance XVI: Information integration in perception and communication* (pp. 125-155). Cambridge, MA: MIT Press.
- Irwin, D. E., Colcombe, A. M., Kramer, A. F., & Hahn, S. (2000). Attentional and oculomotor capture by onset, luminance and color singletons. *Vision Research*, 40, 1443-1458.
- Irwin, D. E., & Gordon, R. D. (1998). Eye movements, attention and transsaccadic memory. *Visual Cognition*, 5, 127-155.
- Irwin, D. E., & Yeomans, J. M. (1986). Sensory registration and informational persistence. *Journal of Experimental Psychology: Human Perception & Performance*, 12, 343-360.
- Irwin, D. E., & Zelinsky, G. J. (2002). Eye movements and scene perception: Memory for things observed. *Perception & Psychophysics*, 64, 882-895.
- Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, 40, 1489-1506.
- Itti, L., & Koch, C. (2001). Computational Modelling of Visual Attention. *Nature Reviews Neuroscience*, 2, 194-203.
- Itti, L., Koch, C., & Niebur, E. (1998). A Model of Saliency-Based Visual Attention for Rapid Scene Analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 20(11), 1254-1259.
- Jackendoff, R., & Landau, B. (1991). Spatial language and spatial cognition. In D. J. Napoli & J. Kegl (Eds.), *Bridges between psychology and linguistics. A Swarthmore festschrift for Lila Gleitman* (pp. 145-169). Hillsdale, NJ: Erlbaum.
- James, W. (1890). *The Principles of Psychology*. New York: Holt.
- Jiang, Y., & Chun, M. M. (2003). Contextual cueing: reciprocal influences between attention and implicit learning. In L. Jimenez (Ed.), *Attention and Implicit Learning* (pp. 277-296). Amsterdam: John Benjamins Publishing Company.

- Jiang, Y., Olson, I. R., & Chun, M. M. (2000). Organisation of visual short-term memory. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 26, 683-702.
- Johnston, J. C. (1981). Understanding word perception: Clues from studying the word superiority effect. In O. Tzeng & H. Singer (Eds.), *Perception of print: Reading research in experimental psychology* (pp. 65-84). Hillsdale, NJ: Erlbaum.
- Johnston, J. C., & McClelland, J. L. (1980). Experimental tests of a hierarchical model of word identification. *Journal of Verbal Learning & Verbal Behavior*, 19, 503-524.
- Jones, E. G., & Powell, T. P. (1970). An anatomical study of converging sensory pathways within the cerebral cortex of the monkey. *Brain*, 93, 793-820.
- Joseph, J. S., Chun, M. M., & Nakayama, K. (1997). Attentional requirements in a 'preattentive' feature search task. *Nature*, 387, 805-807.
- Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object specific integration of information. *Cognitive Psychology*, 24, 175-219.
- Kanwisher, N. G. (1987). Repetition blindness: Type recognition without token individuation. *Cognition*, 27, 117-143.
- Kaplan, R. F., Verfaellie, M., De Witt, L. D., & Caplan, L. R. (1990). Effect of changes in stimulus contingency on visual extinction. *Neurology*, 40, 1299-1301.
- Karacan, H. U., & Hayhoe, M. M. (2008). Is attention drawn to changes in familiar scenes? *Visual Cognition*, 16(2/3), 356-374.
- Karnath, H.-O. (1988). Deficits of attention in acute and recovered visual hemi-neglect. *Neuropsychologia*, 26, 27-43.
- Karnath, H.-O., Himmelbach, M., & Küker, W. (2003). The cortical substrate of visual extinction. *NeuroReport*, 14, 437-442.
- Kelley, T. A., Chun, M. M., & Chua, K.-P. (2003). Effects of scene inversion on change detection of targets matched for visual salience. *Journal of Vision*, 2, 1-5.
- Kinsbourne, M. (1993). Orientational bias model of unilateral neglect: Evidence from attentional gradients within hemispace. In I. H. Robertson & J. C. Marshall (Eds.), *Unilateral Neglect: Clinical and Experimental Studies*. (pp. 63-86). Hove: Laurence Erlbaum Associates.
- Klatzky, R. L., Fikes, T. G., & Pellegrino, J. W. (1995). Planning for hand shape and arm transport when reaching for objects. *Acta Psychologica*, 88, 209-232.
- Klein, R. (1982). Patterns of perceived similarity cannot be generalized from long to short exposure durations and vice versa. *Perception & Psychophysics*, 32, 15-18.

- Koch, C., & Ullman, S. (1985). Shifts in selective visual attention: Towards the underlying neural capacity. *Human Neurobiology, 4*, 219-227.
- Kohler, E., Keysers, C., Umiltà, M. A., Fogassi, L., Gallese, V., & Rizzolatti, G. (2002). Hearing sounds, understanding actions: Action representation in mirror neurons. *Science, 297*, 846-848.
- Kowler, E., Anderson, E., Doshier, B., & Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research, 35*, 1897-1916.
- Kumada, T., & Humphreys, G. W. (2001). Lexical recovery from extinction: neuropsychological evidence for weight linkage in visual selection. *Visual Cognition, 1*, 101-129.
- LaBerge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review, 96*, 101-124.
- Land, M., Mennie, N., & Rusted, J. (1999). The roles of vision and eye movements in the control of activities of daily living. *Perception, 28*, 1311-1328.
- Landau, B., & Jackendoff, R. (1993). What and where in spatial language and spatial cognition. *Behavioral and Brain Sciences, 16*, 217-265.
- Landau, B., Smith, L., & Jones, S. (1998). Object shape, object function and object name. *Journal of Memory and Language, 38*, 1-27.
- Levelt, W. J. M. (1982). Cognitive styles in the use of spatial direction terms. In R. J. Jarvella & W. Klein (Eds.), *Speech, place and action* (pp. 251-268). Chisester, England: Wiley.
- Levelt, W. J. M. (1984). Some perceptual limitations on talking about space. In A. van Doorn, W. van de Grind & J. Koenderink (Eds.), *Limits of perception. Essays in honour of Maarten A Bouman* (pp. 323-358). Utrecht, Netherlands: VNU Science Press.
- Levelt, W. J. M. (1996). Perspective taking and ellipsis in spatial descriptions. In P. Bloom, M. A. Peterson, L. Nadel & M. Garrett (Eds.), *Language and space* (pp. 77-108). Cambridge, MA: MIT Press.
- Levin, D. T., & Simons, D. J. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin & Review, 4*, 501-506.
- Lhermitte, F. (1983). 'Utilization' behaviour and its relations to lesions of the frontal lobes. *Brain, 106*, 237-255.
- Lin, E. L., & Murphy, G. L. (1997). Effects of background knowledge on object categorization and part detection. *Journal of Experimental Psychology: Human Perception & Performance, 23*, 1153-1169.
- Linnell, K. J., Humphreys, G. W., McIntyre, D. B., Laitinen, S., & Wing, A. M. (2005). Action modulates object-based selection. *Vision Research, 45*, 2268-2286.

- Loftus, G. R., & Mackworth, N. H. (1978). Cognitive determinants of fixation location during picture viewing. *Journal of Experimental Psychology: Human Perception & Performance*, 4, 565-572.
- Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom, M. A. Peterson, L. Nadel & M. Garrett (Eds.), *Language and space* (pp. 493-529). Cambridge, MA: MIT Press.
- Logothetis, N. K., & Pauls, J. (1995). Psychophysical and physiological evidence for viewer-centered object representations in the primate. *Cerebral Cortex*, 3, 270-288.
- Logothetis, N. K., & Sheinberg, D. L. (1996). Visual object recognition. *Annual Review of Neuroscience*, 19, 577-621.
- Mack, A., Tang, A., Tuma, R., Kahn, S., & Rock, I. (1992). Perceptual organization and attention. *Cognitive Psychology*, 24, 475-501.
- MacKay, D. (1987). *The Organisation of Perception and Action*. New York: Springer.
- Mackworth, N. H., & Morandi, A. J. (1967). The gaze selects informative details within pictures. *Perception & Psychophysics*, 2, 547-552.
- Madole, K. L., & Cohen, L. B. (1995). The role of object parts in infants' attention to form-function correlations. *Developmental Psychology*, 31, 637-648.
- Madole, K. L., Oakes, L. M., & Cohen, L. B. (1993). Developmental changes in infants' attention to function and form-function correlations. *Cognitive Development*, 8, 189-209.
- Mamassian, P., & Goutcher, R. (2001). Prior knowledge on the illumination position. *Cognition*, 81, B1-B9.
- Mamassian, P., Jentzsch, I., Bacon, B. A., & Schweinberger, S. R. (2003). Neural correlates of shape from shading. *NeuroReport*, 14, 971-975.
- Mandler, J. M., & Parker, R. E. (1976). Memory for Descriptive and Spatial Information in Complex Pictures. *Journal of Experimental Psychology: Human Learning & Memory*, 2(1), 38-48.
- Mandler, J. M., & Ritchey, G. H. (1977). Long-term memory for pictures. *Journal of Experimental Psychology: Human Learning & Memory*, 3, 386-396.
- Marr, D. (1982). *Vision*. San Francisco, CA: W. H. Freeman.
- Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature*, 379, 649-652.
- Matelli, M., Luppino, G., Murata, A., & Sakata, H. (1994). Independent anatomical circuits for reaching and grasping linking the inferior parietal sulcus and inferior area 6 in macaque monkey. *Society for Neuroscience Abstracts*, 20, 404.404.

- Matin, E. (1974). Saccadic suppression: A review and an analysis. *Psychological Bulletin*, 81, 899-917.
- Matsukura, M., Brockmole, J. R., & Henderson, J. M. (2009). Overt Attentional Prioritization of New Objects and Feature Changes during Real-World Scene Viewing. *Visual Cognition*, 17(6/7), 835-855.
- Mattingley, J. B., Davis, G., & Driver, J. (1997). Pre-attentive filling in of visual surfaces in parietal extinction. *Science*, 275, 671-674.
- McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception. Part I: An account of basic findings. *Psychological Review*, 88, 375-407.
- McConkie, G., & Currie, C. (1996). Visual stability across saccades while viewing complex pictures. *Journal of Experimental Psychology: Human Perception & Performance*, 22, 563-581.
- McGrenere, J., & Ho, W. (2000). Affordances: Clarifying and Evolving a Concept. *Proceedings of Graphics Interface 2000, Montreal*, 179-186.
- McManus, I. C., Buckman, J., & Wooley, E. (2004). Is light in pictures presumed to come from the left side? *Perception*, 33, 1421-1436.
- McNaughton, B. L., Barnes, C. A., Gerrard, J. L., Gothard, K., Jung, M. W., Knierim, J. J., et al. (1996). Deciphering the hippocampal polyglot: The hippocampus as a path integration system. *Journal of Experimental Biology*, 199, 173-185.
- Meegan, D. V., & Tipper, P. (1998). Reaching into cluttered visual environments: Spatial and temporal influences of distracting objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 51(A), 225-249.
- Miller, G. A., & Johnson-Laird, P. N. (1976). *Language and Perception*. Cambridge, MA: Harvard University Press.
- Milner, A. D., & Goodale, M. A. (1995). *The Visual Brain in Action*. New York: Academic Press.
- Milner, A. D., Perrett, D. I., Johnston, R. S., Benson, P. J., Jordan, T. R., Heeley, D. W., et al. (1991). Perception and action in 'visual form agnosia'. *Brain* 114, 405-428.
- Milner, A. D., Perrett, D. I., Johnston, R. S., Benson, P. J., Jordan, T. R., Heeley, D. W., et al. (1991). Perception and action in visual form agnosia. *Brain*, 114, 405-428.
- Mishkin, M., & Ungerleider, L. G. (1982). Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behavioural Brain Research*, 6(1), 57-77.
- Mitroff, S. R., & Alvarez, G. A. (2007). Space and time, not surface features, guide object persistence. *Psychonomic Bulletin & Review*, 14, 1199-1204.

- Moore, E., Laiti, L., & Chelazzi, L. (2003). Associative knowledge controls deployment of visual selective attention. *Nature Neuroscience*, 6, 182-189.
- Müller, M. M., Malinowski, P., Gruber T. & Hillyard, S. A. (2003). Sustained division of the attentional spotlight. *Nature*, 424, 309-12.
- Mushiake, H., Tanatsugu, Y., & Tanji, J. (1997). Neuronal activity in the ventral part of premotor cortex during target-reach movement is modulated by direction of gaze. *Journal of Neurophysiology*, 78, 567-571.
- Müsseler, J., & Hommel, B. (1997a). Blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception & Performance*, 23, 861-872.
- Müsseler, J., & Hommel, B. (1997b). Detecting and identifying response compatible stimuli. *Psychonomic Bulletin & Review*, 4, 125-129.
- Neider, M. B., & Zelinsky, G. J. (2006). Scene context guides eye movements during search. *Vision Research*, 46, 614-621.
- Nelson, W. W., & Loftus, G. R. (1980). The functional visual field during picture viewing. *Journal of Experimental Psychology: Human Learning & Memory*, 6, 391-399.
- Neumann, O. (1987). Beyond capacity: A functional view of attention. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 361-394). Hillsdale, NJ: Erlbaum.
- Nickerson, R. S. (1965). Short-term memory for complex meaningful visual configurations: A demonstration of capacity. *Canadian Journal of Psychology*, 19, 155-160.
- Nickerson, R. S. (1968). A note on long-term recognition memory for pictorial material. *Psychonomic Science*, 11, 58.
- Norman, D. A. (1988). *The Psychology of Everyday Things*. New York: Basic Books.
- Norman, D. A. (1990). *The Design of Everyday Things*. New York: Doubleplay.
- Norman, D. A. (1999). Affordances, Conventions, and Design. *Interactions*, 6(3), 38-41.
- Norman, J. (2002). Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *Behavioral and Brain Sciences*, 25, 73-144.
- O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map*. Oxford, England: Clarendon.
- Oliva, A. (2005). Gist of the Scene. In L. Itti, G. Rees & J. K. Tsotsos (Eds.), *Neurobiology of attention* (pp. 251-257). San Diego, CA: Elsevier.

- Oliva, A., & Torralba, A. (2001). Modeling the Shape of the Scene: a Holistic Representation of the Spatial Envelope. *International Journal of Computer Vision*, 42, 145-175.
- Oliva, A., & Torralba, A. (2006). Building the gist of a scene: the role of global image features in recognition. In S. Martinez-Conde, S. L. Macknik, L. M. Martinez, J. M. Alonso & P. U. Tse (Eds.), *Progress in Brain Research* (Vol. 155): Elsevier B. V.
- Oliva, A., Torralba, A., Castelano, M., & Henderson, J. M. (2003). Top-down control of visual attention in object detection. *Proceedings of the IEEE International Conference on Image Processing*, 1, 253-256.
- Palmer, S. E. (1975). The effects of contextual scenes on the identification of objects. *Memory & Cognition*, 3, 519-526.
- Palmer, S. E., & Rock, I. (1994). Rethinking perceptual organisation: The role of uniform connectedness. *Psychonomic Bulletin & Review*, 1, 29-55.
- Parkhurst, D., Law, K., & Niebur, E. (2002). Modeling the role of salience in the allocation of overt visual selective attention. *Vision Research*, 42, 107-123.
- Pashler, H. (1988). Familiarity and visual change detection. *Perception & Psychophysics*, 44, 369-378.
- Pedzek, K., Whetstone, T., Reynolds, K., Askari, N., & Dougherty, T. (1989). Memory for real-world scenes: The role of consistency with schema expectations. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 15, 587-595.
- Peters, R. J., & Itti, L. (2006, March 27-29, 2006). *Computational mechanisms for gaze direction in interactive visual environments*. Paper presented at the 2006 Symposium on Eye Tracking Research and Applications, San Diego, California.
- Peterson, M. S., Kramer, A. F., & Irwin, D. E. (2004). Covert shifts of attention precede involuntary eye movements. *Perception & Psychophysics*, 66, 398-405.
- Phaf, R. H., van der Heijden, A. H. C., & Hudson, P. T. W. (1990). SLAM: A connectionist model for attention in visual selection tasks. *Cognitive Psychology*, 22, 273-341.
- Phillips, J. C., & Ward, R. (2002). S-R correspondence effects of irrelevant visual affordance: Time course and specificity of response activation. *Visual Cognition*, 9, 540-558.
- Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics*, 16, 283-290.

- Pollatsek, A., Rayner, K., & Collins, W. E. (1984). Integrating pictorial information across eye movements. *Journal of Experimental Psychology: General*, 113, 426-442.
- Posner M. I., Snyder C. R. & Davidson B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology*, 109(2), 160-74.
- Potter, M. C. (1975). Meaning in visual search. *Science*, 187, 965-966.
- Potter, M. C. (1976). Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning & Memory*, 2, 509-522.
- Prinz, W. (1990). A common coding approach to perception and action. In O. Neumann & W. Prinz (Eds.), *Relationships between perception and action* (pp. 167-201). Berlin: Springer.
- Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, 9, 129-154.
- Prinz, W., & Hommel, B. (2002). *Attention and Performance XIX: Common mechanisms in perception and action*. Oxford: Oxford University Press.
- Rao, R. P. N., & Ballard, D. H. (1999). Predictive coding in the in the visual cortex: A functional interpretation of some extra-classical receptive-field effects. *Nature Neuroscience*, 2, 79-87.
- Redish, A. D., & Touretzky, D. S. (1997). Cognitive maps beyond the hippocampus. *Hippocampus*, 7, 15-35.
- Rees, G., Wojciulik, E., Clarke, K., Husain, M., Frith, C., & Driver, J. (2000). Unconscious activation of visual cortex in the damaged right hemisphere of a parietal patient with extinction. *Brain*, 123, 1624-1633.
- Regier, T. (1996). *The human semantic potential: Spatial language and constrained connectionism*. Cambridge, MA: MIT Press.
- Regier, T., & Carlson-Radvansky, L. A. (1999). *Attention and vector sum coding in spatial language: An empirical and computational investigation*. Unpublished manuscript, Chicago.
- Rensink, R. A., & Enns, J. (1995). Pre-emption effects in visual search: Evidence for low-level grouping. *Psychological Review*, 102, 101-130.
- Rensink, R. A., O'Regan, J. K., & Clarck, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, 8, 368-373.
- Riddoch, M. J., Bodley Scott, S., & Humphreys, G. W. (2010). No direction home: Extinction is affected by implicit motion. *Cortex*, 46(5), 678-684.
- Riddoch, M. J., Edwards, M. G., Humphreys, G. W., West, R., & Heafield, T. (1998). Visual affordances direct action. Neuropsychological evidence from manual interference. *Cognitive Neuropsychology*, 15, 645-684.

- Riddoch, M. J., Humphreys, G. W., & Edwards, M. G. (2000). Visual affordances and object selection. In S. Monsell & J. Driver (Eds.), *Attention and performance* (Vol. XVIII). Cambridge, MA: MIT Press.
- Riddoch, M. J., Humphreys, G. W., Edwards, S., Baker, T., & Wilson, K. (2003). Seeing the action: Neuropsychological evidence for action-based effects on object selection. *Nature Neuroscience*, 6, 82-89.
- Riddoch, M. J., Humphreys, G. W., Hickman, M., Clift, J., Daly, A., & Colin, J. (2006). I can see what you are doing: Action familiarity and affordance promote recovery from extinction. *Cognitive Neuropsychology*, 23, 583-605.
- Rieser, J. J. (1989). Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 15, 1157-1165.
- Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, 27, 169-192.
- Rizzolatti, G., Riggio, I., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favour of a premotor theory of attention. *Neuropsychologia*, 25, 31-40.
- Robertson, I. H., & North, N. T. (1994). One hand is better than two: motor extinction of left hand advantage in unilateral neglect. *Neuropsychologia*, 32, 1-11.
- Robertson, I. H., Tegner, R., Goodrich, S. J., & Wilson, C. (1994). Walking trajectory and hand movements in unilateral left neglect: A vestibular hypothesis. *Neuropsychologia*, 32, 1495-1501.
- Rock, I. (1974). The perception of disoriented figures. *Scientific American*, 230, 78-85.
- Rock, I. (1983). *The Logic of Perception*. Cambridge, MA: MIT Press.
- Rock, I. (1997). *Indirect perception*. Cambridge, MA: MIT Press.
- Rolls, E. T. (1999). Spatial view cells and the representation of place in the primate hippocampus. *Hippocampus*, 9, 467-480.
- Rolls, E. T., Aggelopoulos, N. C., & Zheng, F. S. (2003). The receptive fields of inferior temporal cortex neurons in natural scenes. *Journal of Neuroscience*, 23, 339-348.
- Rosch, E., Mervis, C., Gray, W., Johnson, D., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology*, 8, 382-439.
- Rosielle, L. J., & Cooper, E. E. (2001). Categorical perception of relative orientation in visual object recognition. *Memory & Cognition*, 29, 68-82.

- Rothkopf, C., Ballard, D., Sullivan, B., & de Barbado, K. (2005). Bayesian modelling of task dependent visual attention strategy in a virtual reality environment. *Journal of Vision*, 5(8), 920.
- Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception. Part 2: The contextual enhancement effect and some tests and extensions of the model. *Psychological Review*, 89, 60-94.
- Schiegg, A., Deubel, H., & Schneider, W. X. (2003). Attentional selection during preparation of prehension movements. *Visual Cognition*, 10, 409-431.
- Schirra, J. (1990). A contribution to reference semantics of spatial prepositions: The visualization problem and its solution in VITRA. In C. Z. Wibbelt (Ed.), *The semantics of prepositions: From mental processing to natural language processing* (pp. 471-515). Berlin: Mouton de Gruyter.
- Schmidt, B. K., Vogel, E. K., Woodman, G. F., & Luck, S. J. (2002). Voluntary and automatic attentional control of visual working memory. *Perception & Psychophysics*, 64, 754-763.
- Schmidt, T. (2002). The finger in flight: Real-time motor control by visually masked colour stimuli. *Psychological Science*, 13, 112-118.
- Schneider, W. X. (1995). VAM: A neuro-cognitive model for visual attention control of segmentation, object recognition and space-based motor action. *Visual Cognition*, 2, 331-376.
- Scholl, B. J. (2000). Attenuated Change Blindness for Exogenously Attended Items in a Flicker Paradigm. *Visual Cognition*, 7(1/2/3), 377-396.
- Schyns, P. G., & Oliva, A. (1994). From blobs to boundary edges: Evidence for time- and spatial-scale-dependent scene recognition. *Psychological Science*, 5, 195-200.
- Sheinberg, D. I., & Logothetis, N. K. (2001). Noticing familiar objects in real world scenes: The role of temporal cortical neurons in natural vision. *Journal of Neuroscience*, 21, 1340-1350.
- Sheliga, B. M., Riggio, L., & Rizzolatti, G. (1994). Spatial attention and eye-movements. *Experimental Brain Research*, 105, 261-275.
- Shelton, A. L., & McNamara, T. P. (2001). Systems of spatial reference in human memory. *Cognitive Psychology*, 43, 274-310.
- Shepard, R. N. (1967). Recognition memory for words, sentences and pictures. *Journal of Verbal Learning & Verbal Behavior*, 6, 156-163.
- Shore, D. I., & Klein, R. M. (2000). The effects of scene inversion on change blindness. *Journal of General Psychology*, 127, 27-43.

- Simon, J. R. (1969). Reaction towards the source of stimulation. *Journal of Experimental Psychology*, 81, 174-176.
- Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science*, 7, 301-305.
- Simons, D. J., & Levin, D. T. (1998). Failure to detect changes to people during a real-world interaction. *Psychonomic Bulletin & Review*, 5, 644-649.
- Snodgrass, J., & Vanderwort, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Human Learning & Memory*, 6, 174-215.
- Song, J. H., & Jiang, Y. (2005). Connecting the past with the present: how do humans match an incoming visual display with visual memory? *Journal of Vision*, 5, 322-330.
- Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs*, 74(11, Whole no. 498).
- Sprague, N., & Ballard, D. (2007). Modelling embodied visual behaviours. *ACM Transactions in Applied Perception*, 4(2), Article 11.
- Standing, L. (1973). Learning 10.000 pictures. *Quarterly Journal of Experimental Psychology*, 25, 207-222.
- Standing, L., Conezio, J., & Haber, R. N. (1970). Perception and memory for pictures: Single-trial learning of 2500 visual stimuli. *Psychonomic Science*, 19, 73-74.
- Sternberg, R. J. (1996). *Cognitive Psychology* (2nd ed.): Harcourt Brace College Publishers.
- Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. In W. G. Koster (Ed.), *Attention and Performance II*. Amsterdam, North Holland: (Reprinted from *Acta Psychologica*, 1969, 30, pp 276-315).
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643-662.
- Stürmer, B., Ascherleben, G., & Prinz, W. (2000). Correspondence effects with manual gestures and postures: A study on imitation. *Journal of Experimental Psychology: Human Perception and Performance*, 26, 1746-1759.
- Symes, E., Ellis, R., & Tucker, M. (2007). Visual object affordances: Object orientation *Acta Psychologica*, 124, 238-255.
- Talmy, L. (1983). How language structures space. In H. L. Pick & L. P. Acredolo (Eds.), *Spatial orientation: Theory, research and application* (pp. 225-282). New York: Plenum Press.
- Tanaka, K. (1996). Inferotemporal cortex and object vision. *Annual Review of Neuroscience*, 19, 109-139.

- Tarr, M. J., Bülthoff, H. H., Zabinski, M., & Blanz, V. (1997). To what extent do unique parts influence recognition across changes in viewpoint? *Psychological Science*, 8, 282-289.
- Tarr, M. J., & Bülthoff, H. H. (1998). Image-based object recognition in man, monkey and machine. *Cognition*, 67, 1-20.
- Tarr, M. J., Williams, P., Hayward, W. G., & Gauthier, I. (1998). Three-dimensional object recognition is viewpoint dependent. *Nature Neuroscience*, 1, 275-277.
- Theeuwes, J. (1991). Exogenous and endogenous control of attention; The effect of visual onsets and offsets. *Perception & Psychophysics*, 49, 83-90.
- Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception & Performance*, 20, 799-806.
- Theeuwes, J., Kramer, A. F., Hahn, S., & Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science*, 9, 379-385.
- Tipper, P., Paul, A., & Hayes, A. E. (2006). Vision-for-action: The effects of object property discrimination and action state on affordance compatibility effects. *Psychonomic Bulletin & Review*, 13(3), 493-498.
- Tipper, S. P. (2004). Attention and Action. In M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences* (3rd ed., pp. 619-629). Cambridge, Massachusetts: MIT Press.
- Tipper, S. P., Howard, L. A., & Houghton, G. (1999). Action-based mechanisms of attention. In G. W. Humphreys, J. Duncan & A. Treisman (Eds.), *Attention, Space and Action* (pp. 232-247). Oxford: Oxford University Press.
- Tipper, S. P., Lortie, C., & Baylis, G. C. (1992). Selective reaching: Evidence for action-centered attention. *Journal of Experimental Psychology: Human Perception & Performance*, 18, 891-905.
- Torralba, A. (2003). Contextual priming for object detection. *International Journal of Computer Vision*, 53, 169-191.
- Torralba, A., & Oliva, A. (2003). Statistics of natural images categories. *Network: Computation in Neural Systems*, 14, 391-412.
- Torralba, A., Oliva, A., Castelano, M., & Henderson, J. M. (2006). Contextual guidance of eye movements and attention in real-world scenes: the role of global features in object search. *Psychological Review*, 113, 766-786.
- Treisman, A. (1988). Features and objects: The Fourteenth Bartlett Memorial Lecture. *Quarterly Journal of Experimental Psychology*, 40A, 201-237.
- Treisman, A. (1998). Feature binding, attention and object perception. *Philosophical Transactions of the Royal Society of London, Series B*, 353, 1295-1306.

- Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12, 97-136.
- Tsagkaridis, K. (2006). *A psychophysical evaluation of perceived lightness in shadow: Exploring the effects of inversion using a variation of Adelson's checkerboard illusion*. (MSc Dissertation, University of Bristol, Bristol).
- Tucker, M., & Ellis, R. (1998). On the Relations Between Seen Objects and Components of Potential Actions. *Journal of Experimental Psychology: Human Perception & Performance*, 24(3), 830-846.
- Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition*, 8, 769-800.
- Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, 116, 185-203.
- Ullmer-Ehrich, V. (1982). The structure of living space descriptions. In R. J. Jarvella & W. Klein (Eds.), *Speech place and action* (pp. 219-249). Chichester, England: Wiley.
- Umiltà, M. A., Kohler, E., Gallese, V., Fogassi, L., Fadiga, L., Keysers, C., et al. (2001). I know what you are doing: A neurophysiological study. *Neuron*, 31, 155-165.
- Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. Analysis of Visual Behavior. In M. A. Ingle, M. I. Goodale & R. J. W. Masfield (Eds.), (pp. 549-586). Cambridge, MA: MIT Press.
- Van Eccelpoel, C., Germeys, F., De Graef, P., & Verfaillie, K. (2008). Coding of identity-diagnostic information in transsaccadic object perception. *Journal of Vision*, 8(14), 1-16.
- Vecera, S. P., & Farah, M. J. (1994). Does visual attention select objects or locations? *Journal of Experimental Psychology: General*, 123(2), 146-160.
- Vidal, J. R., Gauchou, H. L., Tallon-Baudry, C., & O'Regan, J. K. (2005). Relational information in visual short term memory: The structural gist. *Journal of Vision*, 5, 244-256.
- Vo, M. L. H., & Henderson, J. M. (2009). Does Gravity Matter? Effects of Semantic and Syntactic Inconsistencies on the Allocation of Attention during Scene Perception. *Journal of Vision*, 9(3):24, 1-15.
- Ward, R. (1999). Interactions between perception and action systems: a model for selective action. In G. W. Humphreys, J. Duncan & A. Treisman (Eds.), *Attention, Space and Action* (pp. 311-333). Oxford: Oxford University Press.
- Ward, R., & Goodrich, S. J. (1996). Differences between objects and non-objects in visual extinction: A competition for attention. *Psychological Science*, 7, 177-180.

- Ward, R., Goodrich, S. J., & Driver, J. (1994). Grouping reduces visual extinction: Neuropsychological evidence for weight-linkage in visual selection. *Visual Cognition*, 1, 202-238.
- Warrington, E., & James, M. (1967). Tachistoscopic number estimation in patients with unilateral cerebral lesions. *Journal of Neurology, Neurosurgery & Psychiatry*, 30, 468-474.
- Wertheimer, M. (1912). Experimentelle Studien uber das Sehen von Bewegung. *Zeitschrift fur Psychologie*, 61, 161-265.
- Wheeler, M. E., & Treisman, A. M. (2002). Binding in Short-Term Visual Memory. *Journal of Experimental Psychology: General*, 131, 48-64.
- Wickens, T. D. (2002). *Elementary signal detection theory*. New York: Oxford University Press.
- Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review*, 1, 202-238.
- Yantis, S. (1993). Stimulus-driven capture and attentional control settings. *Journal of Experimental Psychology: Human Perception & Performance*, 19, 676-681.
- Yantis, S. (1996). Attentional capture in vision. In A. Kramer, M. Coles & G. Logan (Eds.), *Converging operations in the study of selective visual attention* (pp. 45-76). Washington DC: American Psychological Association.
- Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from selective search. *Journal of Experimental Psychology: Human Perception and Performance*, 22, 1505-1513.
- Yarbus, A. (1967). *Eye movements and vision*. New York: Plenum Press.
- Young, A., & Bion, P. (1979). Hemispheric laterality in the enumeration of visually presented collections of dots by children. *Neuropsychologia*, 17, 99-102.
- Young, M. P. (1995). Open questions about the neural mechanisms of visual pattern recognition In M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences*. Cambridge MA: Bradford.
- Zelinsky, G. J., & Loschky, L. C. (2005). Eye movements serialize memory for objects in scenes. *Perception & Psychophysics*, 67, 676-690.
- Zwaan, R. A. (2004). The immersed experiencer: Toward an embodied theory of language comprehension. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 35-62). New York, NY: Academic Press.

APPENDIX A

Title: Real world scenes rating questionnaire

INSTRUCTIONS

For the following questionnaire you will be presented with some pictures of real world scenes. Within each picture a specific object will be pointed out by a yellow frame drawn around it. You will need to make 2 judgments about each of these objects. · First, you will rate how appropriate it is for the object to be part of that scene. The first judgement pertains to the appropriateness of the object within the context of the scene; the context of the scene refers to its general meaning, as defined by all the objects in it. In other words you are asked to judge how appropriate it is for the specific object to be present in the scene. · Second, you will rate how appropriately the object is placed or positioned for normal (immediate) use. The second judgement pertains to the positioning of the object with regard to physical interaction with it. In other words you are asked to judge how easily you could properly use (or act upon) the specific object if it was in front of you exactly the way it is presented. Please note that there are no right or wrong answers. The various images differ along these two dimensions and you are asked to give your subjective opinion through the rating scale to denote that difference. Don't think too much about it but give a rating according to your first impression. After the first few trials you will get accustomed to the scale and you will be able to give your ratings faster. You will need to judge 120 images, but as long as you do it according to these directions it will not take you more than 20 minutes. You can monitor your progress by the percentage bar on the top of the page. If for some reason you don't have the time to finish the questionnaire you can save your progress at any point and finish it later, although it would be preferable to do it in one session. Your questionnaire is anonymous; you are just required to give some information about characteristics of statistical interest. At the end of the survey you need to add your e-mail address only if you are interested to participate in the draw for one of two £20 vouchers from Amazon.

Thank you in advance for your participation!

APPENDIX B

Paired Samples T-Test – Semantic Consistency

Brockmole & Henderson stimuli left, Action Affordance stimuli right

	Mean	Std. Dev.	T	df	Sig.		Mean	Std. Dev.	t	df	Sig.
animals	5.48980	.73944	51.970	48	.000	bag	.32653	.96583	2.367	48	.022
baking	4.59184	1.49887	21.445	48	.000	bin	.22917	.69158	2.296	47	.026
bar	5.28000	.90441	41.281	49	.000	bucket	.22449	.89595	1.754	48	.086
bathsinktop	4.50000	1.28174	24.825	49	.000	candle	.12245	.88111	.973	48	.336
breakfast	4.39583	1.51221	20.139	47	.000	chair	.16327	.42558	2.685	48	.010
cabinet	4.48980	1.73352	18.130	48	.000	clock	.96000	1.89478	3.583	49	.001
complib	5.10417	.95069	37.197	47	.000	dvd	.06250	.72658	.596	47	.554
computer	4.20833	1.55684	18.728	47	.000	fan	.08163	1.01728	.562	48	.577
copier	4.42000	1.57907	19.793	49	.000	glass	.22917	.66010	2.405	47	.020
dormbathroom	3.44898	1.96915	12.261	48	.000	guitar	-.04082	1.39880	-.204	48	.839
freezer	5.20000	1.12486	32.688	49	.000	iron	-.04000	.69869	-.405	49	.687
fridge	5.61224	.99617	39.437	48	.000	juice	.18000	.80026	1.590	49	.118
garage	5.06122	1.14397	30.970	48	.000	keyboard	.02041	.24915	.573	48	.569
garden	4.30000	1.65677	18.352	49	.000	lamp_shade	.42857	1.24164	2.416	48	.020
ironing	3.93750	1.40525	19.413	47	.000	laptop	.20833	.65097	2.217	47	.031
kitchen	5.18000	1.25666	29.147	49	.000	microphone	.67347	1.47744	3.191	48	.003
lab	4.56000	1.44505	22.313	49	.000	mixer	.20408	.76321	1.872	48	.067
laundromat	3.86000	1.48475	18.383	49	.000	mustard	.20000	.88063	1.606	49	.115
medexam	4.48000	1.80972	17.505	49	.000	pan	.30000	.99488	2.132	49	.038
musicroom	4.92000	1.72426	20.177	49	.000	piggybank	.16000	.54810	2.064	49	.044
nintendo	5.48980	.96009	40.026	48	.000	plate	.08163	.64021	.893	48	.377
picnictable	5.36000	.74942	50.574	49	.000	reading	.18367	.90539	1.420	48	.162
pingpong	5.36735	.85863	43.757	48	.000	shower	.24490	.96890	1.769	48	.083
playground	2.10204	2.04374	7.200	48	.000	soap	.32000	1.16829	1.937	49	.059
pooltable	5.40000	1.08797	35.096	49	.000	screen	.04000	.44994	.629	49	.533
shoes	5.08163	1.20479	29.525	48	.000	teacup	.08163	.49315	1.159	48	.252
stovetop	4.24490	1.95289	15.216	48	.000	toaster	.24490	.80443	2.131	48	.038
toolbox	5.20000	.94761	38.803	49	.000	train	.14583	.65199	1.550	47	.128
weightroom	4.94000	1.13227	30.850	49	.000	tv	.14286	.50000	2.000	48	.051
Workbench	5.18367	.85813	42.284	48	.000	waterfridge	.16327	.94311	1.212	48	.232

Paired Samples T-Test – Action Affordance Consistency
Brockmole & Henderson stimuli left, Action Affordance stimuli right

	Mean	Std. Dev.	t	df	Sig.		Mean	Std. Dev.	T	df	Sig.
animals	3.04082	1.83665	11.589	48	.000	bag	2.22449	2.04395	7.618	48	.000
baking	2.12245	1.84428	8.056	48	.000	bin	4.46939	1.72122	18.177	48	.000
bar	2.40000	1.94831	8.710	49	.000	bucket	3.59184	1.94635	12.918	48	.000
bathsinktop	1.30000	1.78714	5.144	49	.000	candle	4.26531	1.60436	18.610	48	.000
breakfast	1.31915	2.21758	4.078	46	.000	chair	3.83333	1.61553	16.439	47	.000
cabinet	1.20408	2.45781	3.429	48	.001	clock	4.42000	1.83047	17.074	49	.000
complib	1.89583	2.34511	5.601	47	.000	dvd	3.87500	2.04861	13.105	47	.000
computer	1.16327	2.36596	3.442	48	.001	fan	3.73469	1.60436	16.295	48	.000
copier	2.42000	1.92820	8.875	49	.000	glass	3.50000	1.77452	13.665	47	.000
dormbathroom	.67347	2.17359	2.169	48	.035	guitar	3.12245	1.69106	12.925	48	.000
freezer	2.42000	1.99069	8.596	49	.000	iron	3.74000	1.82734	14.472	49	.000
fridge	2.18367	2.25161	6.789	48	.000	juice	3.22000	2.40145	9.481	49	.000
garage	1.46939	2.04228	5.036	48	.000	keyboard	4.34694	1.49375	20.371	48	.000
garden	2.74000	2.08796	9.279	49	.000	lamp_shade	4.08163	1.49773	19.076	48	.000
ironing	1.44898	1.88261	5.388	48	.000	laptop	4.64583	1.40651	22.884	47	.000
kitchen	.98000	2.39464	2.894	49	.006	microphone	1.53061	1.90506	5.624	48	.000
lab	.64000	1.77005	2.557	49	.014	mixer	3.93878	1.56002	17.674	48	.000
laundromat	1.86000	1.92735	6.824	49	.000	mustard	.22000	1.64491	.946	49	.349
medexam	1.38776	2.24366	4.330	48	.000	pan	4.02041	1.33057	21.151	48	.000
musicroom	1.62000	2.59426	4.416	49	.000	piggybank	4.02000	1.62242	17.521	49	.000
nintendto	3.64000	1.95626	13.157	49	.000	plate	4.51020	1.41602	22.296	48	.000
picnictable	2.88000	2.02676	10.048	49	.000	reading_lamp	3.34694	1.49375	15.684	48	.000
pingpong	2.39583	1.83047	9.068	47	.000	shower	5.20408	1.07973	33.739	48	.000
playground	-.14583	1.58436	-.638	47	.527	soap	2.44000	2.22380	7.759	49	.000
pooltable	2.48000	2.20611	7.949	49	.000	screen	2.95918	1.70733	12.133	48	.000
shoes	1.26531	2.25255	3.932	48	.000	teacup	3.51020	1.63455	15.032	48	.000
stovetop	2.57143	2.17945	8.259	48	.000	toaster	3.75510	2.13630	12.304	48	.000
toolbox	1.87755	1.95398	6.726	48	.000	train	4.50000	1.50177	20.760	47	.000
weightroom	1.22449	2.20100	3.894	48	.000	tv	4.46939	1.58248	19.770	48	.000
Workbench	1.95918	2.28180	6.010	48	.000	waterfridge	4.25000	1.73205	17.000	47	.000